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EXPERIMENTAL REVIEW OF TRANSONIC SPILLAGE DRAG OF RECTANGULAR INLETS

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FOREWORD

This report was prepared by North American Aviation, Inc., Los Angeles Division, under Air Force Contract AF 33(615)-2496, "Experimental Study of Additive Drag of Supersonic Propulsion Systems". The report was previously issued as contractor's report NA-66-10 prior to Air Force approval.

The program was sponsored by the Components Branch, Research and Technology Division, Wright-Patterson Air Force Base, Ohio. Program monitor was Mr. H. J. Gratz, APTC. The USAF Project and Task Numbers were, respectively, 3066 and 306603.

The program was initiated on 1 April 1965 and completed on 1 April 1966, and the report was submitted by the authors on 19 May 1966 for approval. Experimental work was carried out during 24 July thru 13 August in the NASA Ames 6' x 6' Supersonic Wind Tunnel with the assistance of NASA personnel R. A. Taylor, Project Coordinator, and C. E. Hedstrom, Project Engineer. Principal contractor personnel were G. C. Tamplin, M. W. Petersen and L. C. Young.

The Aero Propulsion Laboratory, Turbine Engine Components Branch (APTC) is maintaining a copy of the full test program data tape. Information concerning tape availability can be requested thru that office.

Publication of this report does not constitute Air Force approval of the report findings or conclusions. It is published only for the exchange and stimulation of ideas.

Ernest C. Simpson

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ABSTRACT

Inlets sized for supersonic aircraft operation are oversized at transonic speeds. Spilling excess air around the inlet creates spillage drag which can seriously penalize the low altitude penetration range of mixed mission aircraft. Spilling, also creates inlet cowl lip suction forces which can cancel a portion of this drag, but available data on spillage drag and its partial recovery on the cowl lip were not sufficient for necessary design and performance studies. Generalized wind tunnel studies of inlet spillage were required to supply the needed information.

In 1964, NAA/LAD designed and built a "workhorse" model for in-house tests of pitot inlet spillage drag. Under contract AF 33(615)-2496, the "workhorse" portion of this model was fitted with rectangular supersonic inlets. Wind tunnel tests were conducted and are reported herein. Testing was done in the NASA Ames Research Center's 6' x 6' Supersonic Wind Tunnel, primarily in the 0.7 to 1.4 Mach number range. The model had four interchangeable ramps, four sets of side plates and ten interchangeable cowls. The primary test configurations were shock-on-cowl Mach 2.2 and Mach 3.0 design point inlets.

Low drag flow spillage requires decreasing the inlet flow area by (a) increasing the external ramp angle or (b) rotating the cowl inward. Test data show that ramp spillage creates lower total drag. The minimum spillage drag configuration would use minor deflections of both ramp and cowl. However, the cowl actuation weight penalty must be considered.

Experimental transonic ramp pressure drags were normalized and compared with transonic similarity work on wedge airfoils. These ramp drag data, together with cowl drag and spillage drag correction (K_{ADD}) factors developed in this report, are valuable tools for inlet design and performance studies.

TABLE OF CONTENTS

SECTION		PAGE NO.
I	INTRODUCTION	1
II	WIND TUNNEL TEST PHASE SUMMARY	2
III	ADDITIVE DRAG CONCEPT	4
IV	ADDITIVE DRAG RECOVERY	6
V	METHOD OF DETERMINING VALUES OF K_{ADD} AND ΔD_{ADD}	8
VI	CALCULATION OF ΔD_{ADD} THEORY	11
VII	SELECTION OF INLET MASS FLOW RATIO	13
VIII	MEASURED vs. THEORETICAL ADDITIVE DRAG INCREMENT	14
IX	COWL AND SIDE PLATE PRESSURE DRAG	16
X	ADDITIVE DRAG COEFFICIENT, K_{ADD}	17
XI	EFFECT OF SIDE PLATE GEOMETRY ON K_{ADD}	19
XII	RAMP PRESSURE DISTRIBUTIONS	20
XIII	SYNTHESIZING TOTAL INLET DRAG	22
XIV	RAMP DRAG AT $(A_o/A_c)_{REF}$	23
XV	SPILLAGE DRAG COMPARISON - R1SP1C1 THRU R1SP1C6	27
XVI	SPILLAGE DRAG OF VARYING RAMP OR COWL	28
XVII	SPILLAGE DRAG, OF SHARP vs. BLUNT COWL LIPS	30
XVIII	CONCLUSIONS AND RECOMMENDATIONS	31
APPENDIX I	WIND TUNNEL MODEL DESCRIPTION	33
APPENDIX II	THEORETICAL ADDITIVE DRAG COMPUTATION	49
APPENDIX III	COMPILATION OF DATA PLOTS	86
	REFERENCES	158
	DD FORM 1473	161

LIST OF ILLUSTRATIONS

FIGURE NO.	TITLE	PAGE NO.
1	Propulsion Nacelle in Freestream	4
2	Propulsion Nacelle in Freestream	5
3	Subsonic Additive Drag	5
4	Additive Drag Recovery	6
5	Inlet Schematic and Free Body Diagram	8
6	Typical Subsonic Flow Results	10
7	Typical Subsonic K_{ADD}	10
8	Three Flow Regimes	11
9	Wedge Drag	23
10	Inlet Ramp Thickness and Chord	23
11	Ramp Drag where Max $A_o/A_c > (A_o/A_c)_{REF}$	24
12	Ramp Drag where Max $A_o/A_c < (A_o/A_c)_{REF}$	24
13	Sonic Flow at Inlet Lip	25
14	Model Assembly	37
15	Assembly R1SP1C1	39
16	Ramps R1 Thru R4	40
17	Side Plates SP1 Thru SP4	41
18	Cowls C1 Thru C5	42
19	Cowls C6, C7, C8	43
20	Cowls C9, C10	44
21	Ramp Pressures	45
22	External Moveable Ramp Pressures	46
23	Cowl Pressures	47

FIGURE NO.	TITLE	PAGE NO.
24	Side Plate Pressures	48
25	Subsonic Theoretical Additive Drag Momentum Balance	49
26	Supersonic Spillage	51
27	Side Spillage Area	51
28	Side Spillage Conditions	52
29	Flow Field Forward of Terminal Shock (No Side Spillage)	53
30	Subsonic Spillage	53
31	Inlet Supersonic Flow Field and Nomenclature	55
32	Main Program	59-65
33	Main Program Listing	66-71
34	Standard Print Out Format	72
35	Subsonic Case	72
36	Transonic (Detached Shock) Case	73
37	Transonic (Detached Shock) Case	73
38	Supersonic Case	74
39	Print Out Key	75
40	Ideal Deflection Subroutine	78-79
41	Ideal Deflection Subroutine Listing	80-82
42	Side Spillage Subroutine	83
43	Side Spillage Subroutine Listing	84
44	Inlet Nomenclature	85
45	Additive Drag Coeff. Shapes - Measured vs. Theory, $M_o = 0.69$	87

FIGURE NO.	TITLE	PAGE NO.
46	Additive Drag Coeff. Shapes - Measured vs. Theory, M_o = 0.84	88
47	Additive Drag Coeff. Shapes - Measured vs. Theory, M_o = 1.09	89
48	Additive Drag Coeff. Shapes - Measured vs. Theory, M_o = 1.29	90
49	Additive Drag Coeff. Shapes - Measured vs. Theory, M_o = 1.39	91
50	Additive Drag Coeff. Shapes - Measured vs. Theory, M_o = 1.69	92
51	Cowl + Sideplate Drag - R1SP1C1 Thru C6, $\alpha = \beta = 5^o$, M_o = 0.69	93
52	Cowl + Sideplate Drag - R1SP1C1 Thru C6, $\alpha = \beta = 5^o$, M_o = 0.84	94
53	Cowl + Sideplate Drag - R1SP1C1 Thru C6, $\alpha = \beta = 5^o$, M_o = 1.09	95
54	Cowl + Sideplate Drag - R1SP1C1 Thru C6, $\alpha = \beta = 5^o$, M_o = 1.29	96
55	Cowl + Sideplate Drag - R1SP1C1 Thru C6, $\alpha = \beta = 5^o$, M_o = 1.39	97
56	K_{ADD}, R1SP1C1 - C6, M_o = 0.69	98
57	K_{ADD}, R1SP1C1, M_o = 0.69	99
58	K_{ADD}, R1SP1C1, M_o = 0.69	100
59	K_{ADD}, R1SP2C1, M_o = 0.69	101
60	K_{ADD}, R1SP3C1, M_o = 0.71	102
61	K_{ADD}, R2SP1C1, M_o = 0.71	103
62	K_{ADD}, R3SP1C1, M_o = 0.71	104
63	K_{ADD}, R4SP4C1, C6, M_o = 0.71	105

FIGURE NO.	TITLE	PAGE NO.
64	K_{ADD}, R1SP1C1 - C6, M_o = 0.84	106
65	K_{ADD}, R1SP1C1, M_o = 0.84	107
66	K_{ADD}, R1SP1C1, M_o = 0.84	108
67	K_{ADD}, R1SP2C1, M_o = 0.84	109
68	K_{ADD}, R1SP3C1, M_o = 0.865	110
69	K_{ADD}, R2SP1C1, M_o = 0.865	111
70	K_{ADD}, R3SP1C1, M_o = 0.865	112
71	K_{ADD}, R4SP4C1, C6, M_o = 0.865	113
72	K_{ADD}, R4SP4C6, M_o = 0.865	114
73	K_{ADD}, R4SP4C1, C6, M_o = 0.865	115
74	K_{ADD}, R1SP1C1 - C6, M_o = 1.09	116
75	K_{ADD}, R1SP1C1, M_o = 1.09	117
76	K_{ADD}, R1SP1C1, M_o = 1.09	118
77	K_{ADD}, R1SP2C1, M_o = 1.09	119
78	K_{ADD}, R1SP3C1, M_o = 1.11	120
79	K_{ADD}, R3SP1C1, M_o = 1.11	121
80	K_{ADD}, R4SP4C1, C4, C6, M_o = 1.11	122
81	K_{ADD}, R4SP4C6, M_o = 1.11	123
82	K_{ADD}, R4SP4C1, C4, M_o = 1.11	124
83	K_{ADD}, R1SP1C1-C6, M_o = 1.29	125
84	K_{ADD}, R1SP2C1, M_o = 1.29	126
85	K_{ADD}, R1SP3C1, M_o = 1.31	127
86	K_{ADD}, R2SP1C1, M_o = 1.31	128
87	K_{ADD}, R3SP1C1, M_o = 1.31	129

FIGURE NO.	TITLE	PAGE NO.
88	K_{ADD}, R4SP4C1, C4, C6, M_o = 1.31	130
89	K_{ADD}, R1SP1C1-C6, M_o = 1.39	131
90	K_{ADD}, R1SP2C1, M_o = 1.39	132
91	K_{ADD}, R1SP[illegible]C1, M_o = 1.41	133
92	K_{ADD}, R3SP1C1, M_o = 1.41	134
93	K_{ADD}, R4SP4C1, C4, C6, M_o = 1.41	135
94	K_{ADD}, R1SP1C1, C5, M_o = 1.69	136
95	Cowl Centerline Pressure Distribution	137
96	K_{ADD}, Several Side Plates, M_o = 0.7	138
97	K_{ADD}, Several Side Plates, M_o = 0.85	139
98	K_{ADD}, Several Side Plates, M_o = 1.1	140
99	K_{ADD}, Several Side Plates, M_o = 1.3	141
100	K_{ADD}, Several Side Plates, M_o = 1.4	142
101	Ramp Pressure Distribution R1SP1C1; $\alpha = \beta = 5^\circ$; M_o = 0.84	143
102	Ramp Pressure Distribution R1SP1C1; $\alpha = 5^\circ$, $\beta = 12^\circ$; M_o = 0.84	144
103	Ramp Pressure Distribution R1SP2C1; $\alpha = \beta = 5^\circ$; M_o = 0.84	145
104	Ramp Pressure Distribution R1SP3C1; $\alpha = \beta = 5^\circ$, M_o = 0.865	146
105	Ramp Pressure Distribution R1SP1C1; $\alpha = \beta = 5^\circ$; M_o = 1.29	147
106	Ramp Pressure Distribution R1SP1C1; $\alpha = 5^\circ$, $\beta = 12^\circ$; M_o = 1.29	148
107	Ramp Pressure Distribution R1SP2C1; $\alpha = \beta = 5^\circ$; M_o = 1.29	149

FIGURE NO.	TITLE	PAGE NO.
108	Ramp Pressure Distribution R1SP3C1; $\alpha = \beta = 5^{\circ}$; $M_0 = 1.31$	150
109	Suggested Reference Ramp Drag, $(D_R)_{REF}$	151
110	Inlet Total Drag, R1SP1C1-C6, $M_0 = 0.84$	152
111	Inlet Total Drag, R1SP1C1-C6, $M_0 = 1.29$	153
112	Spillage by Varying Ramp and Cowl, $M_0 \approx .85$	154
113	Spillage by Varying Ramp and Cowl, $M_0 \approx 1.1$	155
114	Spillage by Varying Ramp and Cowl, $M_0 \approx 1.3$	156
115	Drag Comparison, Sharp vs. Blunt Cowls, $M_0 = 0.85, 1.29$	157

LIST OF TABLES

TABLE NO.	TITLE	PAGE NO.
I	Machine Program Subroutines	58
II	Print Out Definitions	76-77

LIST OF ABBREVIATIONS AND SYMBOLS

ITEM	DEFINITIONS
a	Most aft external station of force model exposed to flow.
A	Area.
A^*	Sonic flow area.
A_c	Inlet capture area. The frontal projected area of an inlet, in the freestream velocity vector direction, bounded by the cowl leading edge, side plate leading edges and initial ramp leading edge.
A_e	Exit area.
A_{LIP}	Cowl lip station inlet area.
A_o	Airflow streamtube area in the freestream.
A_o/A_c	Inlet mass flow ratio; mass flow entering the inlet ratioed to capture area of the inlet.
$(A_o/A_c)_{MAX\ COMPUTED}$	The inlet maximum mass flow ratio computed from the Supersonic Mathematical Model of Appendix II.
$(A_o/A_c)_{REF}$	Reference mass flow ratio of the inlet.
∂A	Infinitesimal area.
c	Ramp or wedge chord length.
$C_{C_{ADD}}$	Chord direction additive drag coefficient.
$\left[C_{C_C} + C_{C_S}\right]$	Cowl plus side plate pressure drag integration coefficient in D/q_oA_c form.
C_{C_e}	N/q_oA_c.
D	Drag.

D_{ADD}	Additive Drag.
ΔD_{ADD}	The change in additive drag between inlet operation at (A_o/A_c) and $(A_o/A_c)_{REF}$.
$D_{ADD\ THEORY}$	Theoretical additive drag.
$\Delta D_{ADD\ THEORY}$	The change in theoretical additive drag between inlet operation at (A_o/A_c) and $(A_o/A_c)_{REF}$.
$(D_{ADD\ THEORY})_{REF}$	Theoretical additive drag at $(A_o/A_c)_{REF}$.
$(D_{ADD})_{REF}$	Additive drag at $(A_o/A_c)_{REF}$.
D_f	Friction drag.
$(D)_{REF}$	Drag at $(A_o/A_c)_{REF}$.
D_R	Ramp drag.
$(D_R)_{REF}$	Ramp drag at $(A_o/A_c)_{REF}$.
D_{TOTAL}	Total inlet drag.
f, f'	General mathematical functions.
F_{BAL}	Balance force.
F_{INT}	See equation 1.
F_N	Net thrust.
$(F_{INT})_{COR}$	See equations 2 and 3.
g	Gravitational constant.
H	Total pressure.
K_{ADD}	Additive drag correction factor (see equation 4).
L.E.	Leading Edge.

M	See equations 8 and 9.
M	Mach number, always used with subscript.
M_e	Exit station Mach number.
M_o	Freestream Mach number.
M_{LIP}	Mach number at the cowl lip station.
N	A drag as defined by equation 6.
N_{REF}	Value of N at $(A_o/A_c)_{REF}$.
ΔN	Change in value of N between (A_o/A_c) and $(A_o/A_c)_{REF}$.
P	Pressure.
P_e	Pressure at an exit station.
P_{LIP}	Cowl lip station pressure.
P_o	Freestream pressure.
P_R	Pressure on inlet ramp.
dP/dx	Rate of change of pressure with axial distance.
q_o	Freestream dynamic pressure.
s	Stagnation.
t	Ramp or wedge thickness.
V_o, V_e	Freestream and exit velocities, respectively.
W_o, W_e	Weight rate of airflow entering and exiting from a control volume at freestream and exit stations.
α	Angle of the initial inlet ramp relative to the freestream velocity vector.

β	Angle of the second external inlet ramp relative to the freestream velocity vector.
Δ	Change in a quantity.
γ	Ratio of specific heats.

SUBSCRIPTS

ITEM	DEFINITION
e	Exit station conditions.
o	Freestream station conditions.
B1, B2	Denotes base areas 1 and 2.
LIP	Denotes a quantity at the cowl lip station of an inlet.
NS	Denotes conditions behind a normal shock wave.
R	Denotes conditions on inlet ramp.
REF	Denotes quantity at $(A_o/A_c)_{REF}$.

Special nomenclature used in Appendixes I, II and III have not been included. All important nomenclature is either fully explained in the text of the Appendixes or a special nomenclature listing is given.

I

INTRODUCTION

The objectives of this work were (1) the experimental study of inlet geometric factors affecting spillage drag of rectangular supersonic inlets and (2) the conversion of measured data to correction factors which may be applied to calculated theoretical additive drag values to realistically estimate spillage drag and improve the accuracy of inlet-engine performance predictions.

Previous experimental work, references 1 thru 10, has generally been restricted to drag studies of complete airplane configurations. This means that a wide variation of inlet geometric factors were not considered, and, more importantly, that a relatively small error in measurement of complete configuration drag creates a large spillage drag inaccuracy. If spillage drag is ten percent of the total vehicle drag, an error of only one percent in total drag measurement precludes meaningful spillage drag studies of many inlet geometric variations.

The wind tunnel test model used in this investigation was an inlet model only, not a full configuration model. The model was constructed so that a number of inlet cowls, side plates and external initial ramps could be interchanged and tested.

The test Mach number range was primarily limited to Mach 0.7 to Mach 1.4. At lower Mach numbers, spillage drag is seldom of importance, and at higher Mach numbers it is generally felt that theoretical predictions of spillage drag are reasonably accurate.

The wind tunnel test phase is briefly summarized in Section II. Sections III thru VII are background information for the experimental results given in the later portion of this report.

II

WIND TUNNEL TEST PHASE SUMMARY

1. Model. A comprehensive description of the wind tunnel force model used in the investigation is given in Appendix I. It was a rectangular, supersonic inlet model having two external ramps. The second external ramp was variable from 5° to 12° relative to the freestream vector. The inlet was constructed so that several cowls, side plates and fixed initial ramps could be interchanged. Ten cowls, C1 thru C10, four fixed initial ramps, R1 thru R4, and four side plate sets, SP1 thru SP4, were tested.

2. Wind Tunnel. Testing was conducted in the continuous flow NASA Ames 6' x 6' Supersonic Wind Tunnel. Nominal test conditions were

M_0	Total Press.
0.7	1960 psf
0.85	1960
1.1	1400
1.3	1400
1.4	1475
1.7	1335
2.2	2190

3. Configurations Tested. The following listing summarizes the configurations and Mach numbers at which data were obtained. The ramp, side plate, and cowl configurations listed are illustrated in Appendix I. Angles of the initial and second ramps are α and β , respectively, with respect to the freestream vector.

Test Mach Numbers

Config.	Design M_0	α	β	.70	.85	1.1	1.3	1.4	1.7	2.2
R1SP1C1	3.0	5°	5°	x	x	x	x	x	x	x
			9°	x	x	x	x	x		
			12°	x	x	x	x	x		
R1SP1C2			5°	x	x	x	x	x		
R1SP1C3				x	x	x	x	x		
R1SP1C4				x	x	x	x	x		
R1SP1C5				x	x	x	x	x	x	
R1SP1C6				x	x	x	x	x		
R1SP1C7				x	x	x	x		x	
R1SP1C8				x	x	x	x	x	x	
R1SP1C9				x	x	x	x	x		
R1SP1C10				x	x	x	x	x		
R1SP2C1				x	x	x	x	x		
			12°	x	x	x	x			
R1SP3C1			5°	x	x	x	x	x		
R1SP1SP3C1							x	x	x	

Test Mach Numbers

Config.	Design M_0	α	β	.70	.85	1.1	1.3	1.5	1.7	2.2
R2SP1C1	2.2	7°	7°	x	x		x			
R3SP1C1	—	12°	12°	x	x	x	x	x		
R4SP4C1	—	5°	5°	x	x	x	x	x		
↓	↓	↓	12°		x	x	x			
R4SP4C4	—	↓	5°	x	x	x	x	x		
↓	↓	↓	9°				x	x		
R4SP4C6	—	↓	5°	x	x	x	x	x		
↓	↓	↓	9°		x	x	x	x		
↓	↓	↓	12°		x	x	x			

As indicated in the second column, inlets having R1 were shock-on-cowl design point inlets for Mach 3.0. Inlets having R2 were shock-on-cowl at Mach 2.2. R3 and R4 first ramps had their leading edges at the same station as R1 as shown on figure 16. The R3 and R4 ramp configurations were included to show the effects of first ramp angle.

Since the model did not have boundary layer control features, subcritical stability at Mach 2.2 was limited. No analysis of these data was worthwhile. Analysis of the four sets of Mach 1.7 data was limited because of tunnel flow problems as explained later.

III

ADDITIVE DRAG CONCEPT

The additive drag concept is fully accepted in calculating airplane performance although no real counterpart of the concept exists in nature. It is a thrust-drag bookkeeping tool which conveniently bridges the gap between the engine manufacturer's definition of net thrust, F_N, and the airframe manufacturer's requirement for internal thrust, F_{INT}, for airplane performance prediction.

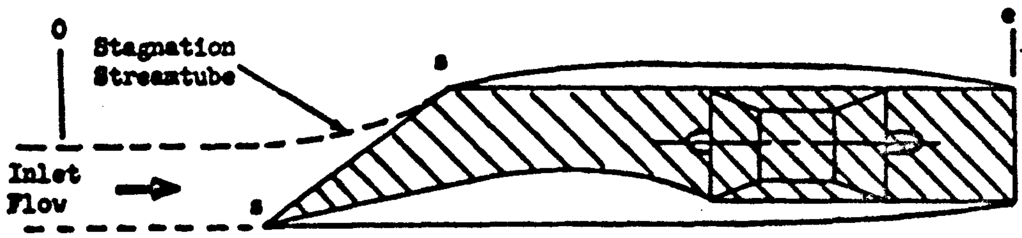


Figure 1 . Propulsion Nacelle in Freestream

The airframe manufacturer requires evaluation of F_{INT}

$$F_{INT} = (INT)\int_{s}^{e} (P - P_o)dA$$

P — local static pressure
dA — incremental frontal area

where the integral is taken around all of the internal surfaces of the propulsion system. The integral region is shown on figure 1 as the cross-hatched area extending from streamtube stagnation, s, on inlet leading edges to the exit from the nacelle. F_{INT} is the internally generated thrust which provides the propelling force for the airplane, but it is not evaluated by performing the complex internal integration. Instead, the starting point is the engine manufacturer's net thrust

$$F_N = \left[(P_e - P_o)A_e + W_eV_e/g\right] - \left[(P_o - P_o)A_o + W_oV_o/g\right]$$

A force-momentum balance on the cross-hatched free body of figure 2 illustrates that F_{INT} is evaluated by subtracting "drag" of the unbounded streamtube from F_N:

$$F_{INT} = F_N - \int_{o}^{s} (P - P_o)dA = F_N - D_{ADD} \qquad \text{Eq. (1)}$$

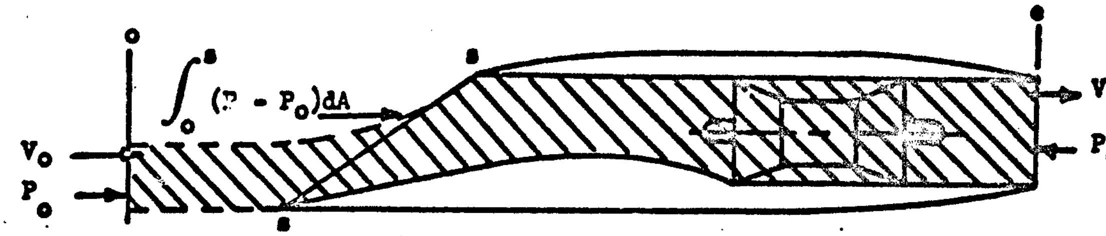


Figure 2 . Propulsion Nacelle in Freestream

This unbounded streamtube "drag" is termed additive drag, D_{ADD},

$$D_{ADD} = \int_o^s (P - P_o)dA$$

D_{ADD} is not felt on an aircraft surface , but it must be subtracted from F_N to obtain the required F_{INT} force-momentum balance.

Detailed examination of the D_{ADD} integral shows additive drag to be caused by airflow spillage around the inlet. Figure 3 illustrates that for the no spillage case, $A_o/A_c = 1.0$, D_{ADD} is zero because the streamtube has no frontal area for drag to occur. As mass flow is reduced, drag area of the streamtube increases, static pressure within the streamtube increases, and D_{ADD} can become large. Spillage causes additive drag at supersonic speeds as well as at the subsonic speeds used in the illustration.

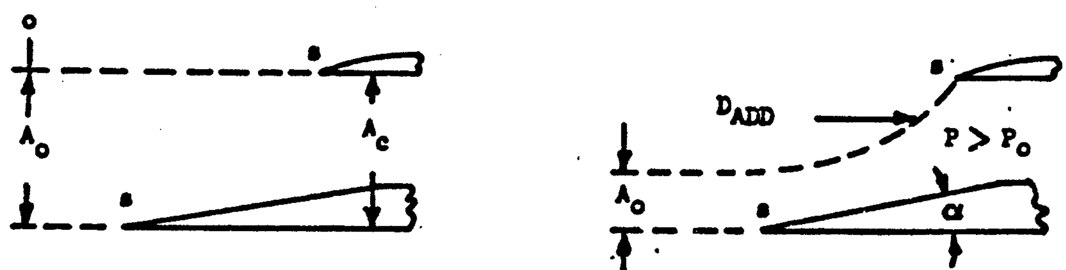


Figure 3 . Subsonic Additive Drag

External geometry of the inlet affects the magnitude of the D_{ADD} integral over the streamtube. A given spillage can be obtained with various external ramp and inlet side plate geometries. Ramp angle may be raised or lowered; side plates may be cut-back, allowing side spillage, or extended. Each external inlet geometry creates a particular stagnation streamtube shape and particular flow conditions within the streamtube. In magnitude, D_{ADD} is a function of both the amount of spillage and the way it is spilled (external inlet geometry).

IV

ADDITIVE DRAG RECOVERY

The full value of D_{ADD} should rarely be charged as a penalty to the airplane at subsonic and low supersonic speeds. Air spilling around the inlet increases velocity and decreases pressure on the leading portions of cowl and side plates. At reduced mass flow ratios surface pressures drop below ambient, and these surfaces produce thrust rather than drag. This is illustrated in figure 4 by a typical subsonic data sample from this research program. Part of the D_{ADD} spillage drag penalty is offset by spillage thrust created by suction on cowl and side plate lips.

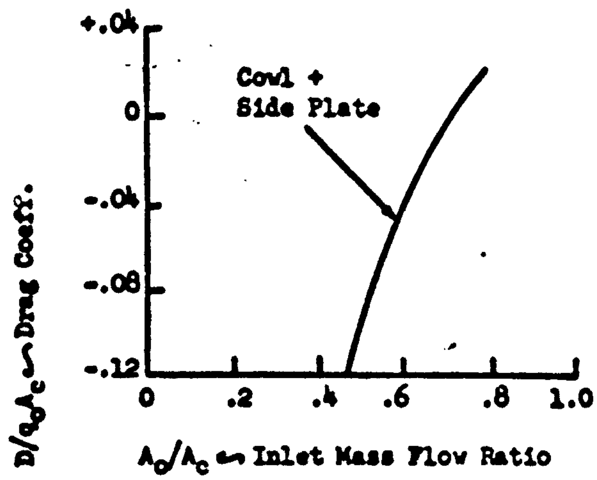


Figure 4 . Additive Drag Recovery

In airplane thrust-drag bookkeeping, it is usual practice to consider external airplane drag as invariant with inlet mass flow ratio. Thrust-drag items which do vary with mass flow ratio are included within the scope of the propulsion system performance. Thus, for a given flight condition a fixed airplane external drag is assigned, corresponding to operation at a given inlet reference mass flow ratio. Then, rather than equation 1, a new equation of the form

$$(F_{INT})_{COR} = F_N - f\left[D_{ADD} - (D_{ADD})_{REF}\right] = F_N - f\,(\Delta D_{ADD}) \qquad \text{Eq. (2)}$$

is used to represent the propulsion system.

Equation 2 is an idealized situation because $f(\Delta D_{ADD})$ of the particular airplane is presumed to be known. This requires the construction and testing of a ducted aerodynamic force model of the given configuration over the required range of inlet mass flow ratio. Much more frequent is performance prediction for "drawing board" airplanes, and such data is unavailable.

In practice then, equation 2, is modified to become

$$(F_{INT})_{COR} = F_N - f'\left[D_{ADD\ THEORY} - (D_{ADD\ THEORY})_{REF}\right] \quad \text{Eq. (3)}$$
$$= F_N - f'\ (\Delta D_{ADD\ THEORY})$$

A theoretical computed additive drag is substituted for actual additive drag. The f' factor is selected from previous test data of inlets as nearly like the one in question as obtainable. Obviously, if ($D_{ADD\ THEORY}$) duplicates D_{ADD}, the desired f' and f factors are identical. In the remainder of this report, the f' factor will be called the <u>additive drag correction factor</u> and will be symbolized as K_{ADD}, conforming to the usage in published literature:

$$(F_{INT})_{COR} = F_N - K_{ADD}\ (\Delta D_{ADD\ THEORY}) \qquad \text{Eq. (4)}$$

It is desirable that the theoretical and actual additive drags be in reasonable agreement. Only then will K_{ADD} retain the physical significance of the f function of equation 2. A later section deals with the theoretical additive drag calculations used for this project and compares theoretical and "measured" additive drags.

V

METHOD OF DETERMINING EXPERIMENTAL VALUES OF K_{ADD} AND ΔD_{ADD}

Figure 5 shows a schematic of the test phase wind tunnel force model and a free body diagram of the force-momentum balance which was solved to determine K_{ADD} and ΔD_{ADD}. In addition to instrumentation for determination of station o and station e conditions, base pressures and balance force, static pressure instrumentation was required on the cowl and side plate lip regions so that numerical integrations of cowl and side plate pressure drag could be made. This latter instrumentation is described in Appendix I.

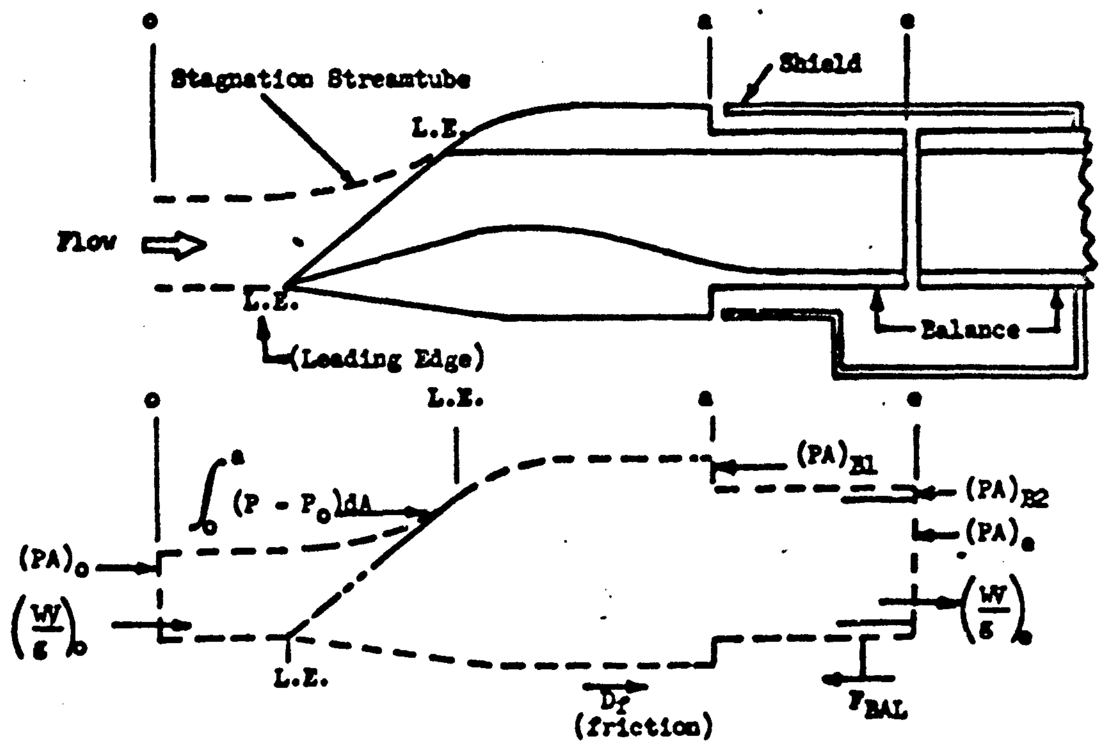


Figure 5 . Inlet Schematic and Free Body Diagram

From figure 5 , the chord direction force-momentum balance, the quantity

$$\int_o^a (P - P_o)dA + D_f$$

can be evaluated as

$$\int_0^a (P - P_o)dA + D_f = F_{BAL} - (W/g)_o + (P_e - P_o)A_e + (W/g)_e + \sum_{BASES} (P_{BASE} - P_o)A_{BASE} = N \qquad \text{Eq. (5)}$$

By separating the integral into three components, streamtube drag, cowl and side plate drag, and drag of the under-body of the model

$$\int_0^{L.E.} (P - P_o)dA + \left[\int (P - P_o)dA\right]_{\substack{\text{Cowl +}\\ \text{Side Plate}}} + \left[\int (P - P_o)dA\right]_{\substack{\text{under-}\\ \text{body}}} + D_f = N$$

Then, considering both the change in friction with mass flow ratio and the change in pressure drag of the under-body with mass flow ratio to be negligible

$$D_{ADD} + \left[\int (P - P_o)dA\right]_{\substack{\text{Cowl +}\\ \text{Side Plate}}} + (\text{CONST.}) = N \qquad \text{Eq. (6)}$$

From equation 6, it is clear that the change in N with mass flow is identical with the change in unrecovered additive drag with mass flow, and

$$K_{ADD} = \frac{N - N_{REF}}{\Delta D_{ADD\ THEORY}} = \frac{\Delta N}{\Delta D_{ADD\ THEORY}} \qquad \text{Eq. (7)}$$

where

N_{REF} ↝ value of N at the reference inlet mass flow ratio, $(A_o/A_c)_{REF}$

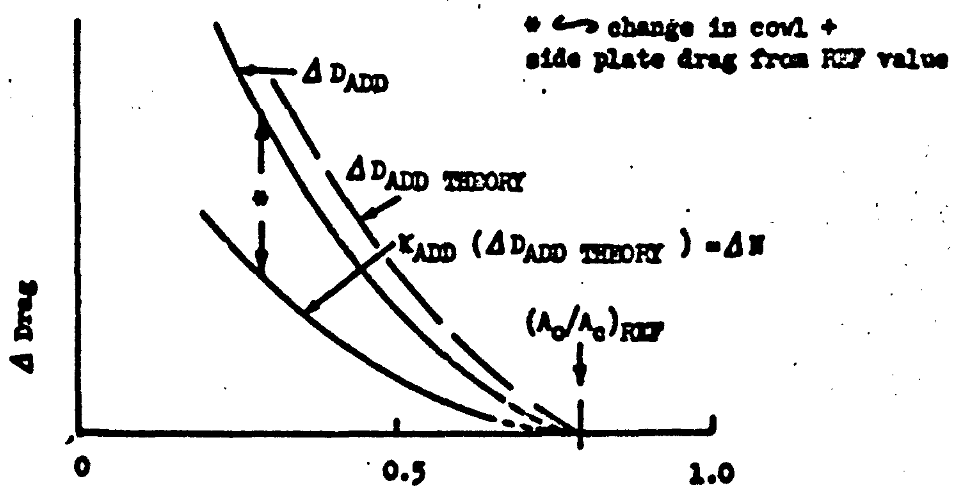
The quantity ΔD_{ADD} was found by substituting into equation 6 the numerically integrated values of cowl and side plate pressure drag

$$D_{ADD} + (\text{CONST.}) = N - \begin{bmatrix}\text{Cowl + Side Plate}\\ \text{Numerical Pressure}\\ \text{Drag Integration}\end{bmatrix} = M \qquad \text{Eq. (8)}$$

Then,

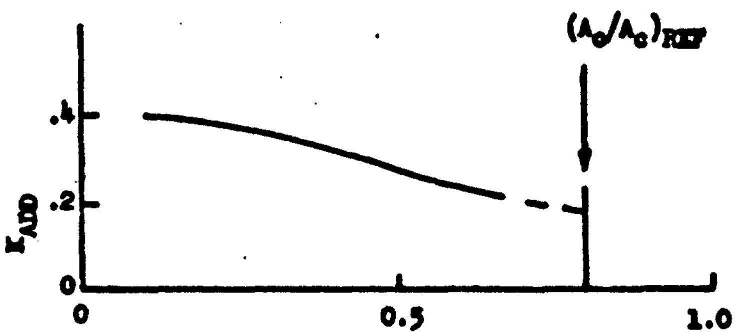
$$\Delta D_{ADD} = M - M_{REF} = \Delta M \qquad \text{Eq. (9)}$$

Figures 6 and 7 illustrate a typical relation between ΔD_{ADD}, $\Delta D_{ADD\ THEORY}$, $K_{ADD}(\Delta D_{ADD\ THEORY})$, and K_{ADD} found for subsonic flow situations. The short (dotted) extrapolations of measured data shown in figure 6 were normally required to reach the selected inlet reference mass flow ratio.



A_o/A_c ⟷ Inlet Mass Flow Ratio

Figure 6 . Typical Subsonic Flow Results



A_o/A_c ⟷ Inlet Mass Flow Ratio

Figure 7 . Typical Subsonic K_{ADD}

Comparisons of ΔD_{ADD} data and $\Delta D_{ADD\ THEORY}$ are examined in Section VIII. A detailed discussion of the mathematical models and computer program for $\Delta D_{ADD\ THEORY}$ is given in Appendix II. The mathematical models for $\Delta D_{ADD\ THEORY}$ were deliberately simplified to allow hand calculations.

VI

CALCULATION OF $\Delta D_{ADD\ THEORY}$

Mathematical models were devised for the calculation of $D_{ADD\ THEORY}$. The models were kept reasonably simple to allow hand computations by the user. However, because of the large number of calculations involved in data analyses, a Fortran IV computer program was written and used. Both mathematical models and computer program are described in detail in Appendix II.

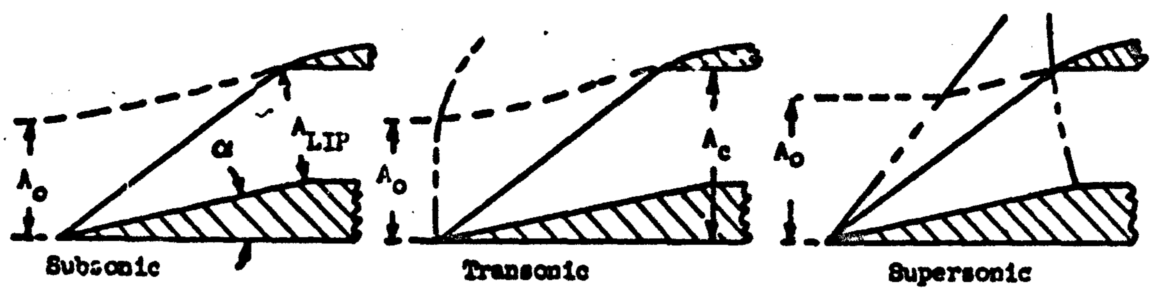


Figure 8 . Three Flow Regimes

Three mathematical models were constructed: a subsonic, a transonic (detached shock wave), and a supersonic model. Figure 8 illustrates the three flow regimes.

The subsonic model considers that flow rotates α degrees from freestream to ramp direction without increasing ramp pressure. Ramp pressure is a lumped parameter defined as

$$P_R = (P_o + P_{LIP})/2$$

where P_{LIP} is a function of mass flow ratio only. All flow enters the inlet in direction α , and the subsonic flow field is considered isentropic and one-dimensional.

In reality, a force is required to rotate the flow from the freestream to the ramp direction. Ramp pressures even at maximum mass flow ratio, M_{LIP} = 1.0, will rise above P_o locally. Side spillage of airflow from the higher pressure ramp to the freestream will occur, but side spillage does not affect the maximum inlet mass flow ratio in a subsonic flow field. Therefore, the simplifying assumption of one-dimensional flow is used in the mathematical model, and side spillage is neglected.

For the transonic model a (non-isentropic) normal shock wave is added forward of the inlet, and ramp pressure is defined as $(P_{NS} + P_{LIP})/2$.

The supersonic case treats additive drag from three spillages:

1) supersonic spillage over the cowl,
2) subsonic spillage over the cowl and
3) supersonic spillage around the side plate from the supersonic region forward of the terminal shock wave.

The maximum mass flow ratio and associated drag are computed considering the side spillage.

For data analysis, $D_{ADD\ THEORY}$ and $(D_{ADD\ THEORY})_{REF}$ were individually computed using the spillage models. Then $\Delta D_{ADD\ THEORY}$ was determined by

$$\Delta D_{ADD\ THEORY} = D_{ADD\ THEORY} - (D_{ADD\ THEORY})_{REF} \qquad \text{Eq. (10)}$$

VII

SELECTION OF THE INLET REFERENCE MASS FLOW RATIO

Several factors were considered in the selection of $(A_o/A_c)_{REF}$. A listing of the desirable characteristics of the reference value should include:

1) The reference A_o/A_c should be a uniquely definable flow condition, not some arbitrary fraction of A_c;
2) The reference should not be restrictive of side plate geometry, ramp angle or ramp length;
3) The reference should be a computed rather than a measured value since, in most cases, the user will not have a measured reference value;
4) The reference mass flow ratio should not be smaller than the normal operating mass flow ratio of the inlet since K_{ADD} is not defined above $(A_o/A_c)_{REF}$;
5) The reference mass flow ratio should not be so large that extrapolated data are physically unrealistic.

These factors suggest one of two maximums, the first being a computed value of maximum inlet flow, the second being the largest mass flow ratio at which the inlet may be expected to operate.

For the subsonic regime the selected reference mass flow ratio is

$$(A_o/A_c)_{REF} = A_{LIP}/A_c \qquad \text{Eq. (11)}$$

This represents $M_{LIP} = M_o$ and $P_{RAMP} = P_o$. The measured maximum mass flow ratio at $M_o = 0.69$ for the basepoint configuration, R1SP1C1 and $\alpha = \beta = 5^\circ$, was one-half percent larger than the reference value. Normally, boundary layer, internal contraction in the inlet, and "sharp lip losses" dictate inlet operation below the reference.

For the transonic regime, the same reference is used

$$(A_o/A_c)_{REF} = A_{LIP}/A_c$$

The supersonic regime requires a different reference. Maximum mass flow ratio computed from the Supersonic Mathematical Model of Appendix II was selected:

$$(A_o/A_c)_{REF} = (A_o/A_c)_{MAX\ COMPUTED} \qquad \text{Eq. (12)}$$

Although supersonic side spillage was considered in computing the maximums, boundary layer and inlet internal contraction caused measured maximums to be several percent lower than the computed reference values for the basepoint inlet at Mach 1.3 and 1.4.

The difference between the reference value and the measured maximums for the basepoint inlet can be seen on figures 45 thru 50 of Appendix III.

VIII

MEASURED vs. THEORETICAL ADDITIVE DRAG INCREMENT

Equation 8 shows how the D_{ADD} curve shape can be obtained from experimental data. Written in terms of drag coefficient, the equation becomes

$$(D_{ADD})/q_oA_c+(\text{CONST.}) = N/q_oA_c - \begin{bmatrix}\text{Cowl + Side Plate}\\ \text{Numerical Pressure}\\ \text{Drag Integration}\end{bmatrix} = C_{C_e} - \left[C_{C_C} + C_{C_S}\right]$$

Plots of this equation as a function of mass flow ratio for configurations R1SP1C1 thru C6 where $\alpha = \beta = 5^o$ are shown on figures 45 thru 50 for the six test Mach numbers between 0.69 and 1.69. The change in

$$\left\{C_{C_e} - \left[C_{C_C} + C_{C_S}\right]\right\}$$

with mass flow ratio is identical with the change in $(D_{ADD})/q_oA_c$ or $(\Delta D_{ADD})/q_oA_c$ with mass flow ratio. Since additive drag is relatively independent of cowl shape, conglomerate plots of data for all six cowls can be made at each Mach number.

Plots of $D_{ADD\ THEORY}$ (or $\Delta D_{ADD\ THEORY}$) adjusted in absolute value to correspond with the measured data at $(A_o/A_c)_{REF}$ are also given on the figures so that a direct comparison between ΔD_{ADD} and $\Delta D_{ADD\ THEORY}$ can be made. Except for Mach 1.69, the figures show the measured and theoretical curve shapes and slopes to be very similar. This means that K_{ADD} curves maintain much physical significance even though they are obtained from $\Delta D_{ADD\ THEORY}$, not ΔD_{ADD}.

For the subsonic cases where $\Delta D_{ADD\ THEORY}$ lies above ΔD_{ADD},

$$\frac{\Delta D_{ADD}}{\Delta D_{ADD\ THEORY}} < 1$$

and K_{ADD} values should be less than 1.0.

For the supersonic cases ΔD_{ADD} lies above $\Delta D_{ADD\ THEORY}$. Therefore

$$\frac{\Delta D_{ADD}}{\Delta D_{ADD\ THEORY}} > 1$$

and K_{ADD} values may be greater than 1.0.

In view of realistic flow situations, agreement between measured values and theoretical values is remarkably good.

The few cases of Mach 1.69 test data included in this report have questionable validity. Tunnel flow problems were encountered at this Mach number. Shadowgraph pictures taken during the testing show that a shock wave from the tunnel wall struck the model several inches forward of the cowl lip during two of the data runs. During the other two Mach 1.69 data runs there was a change in flow augularity relative to the model as a function of time. For these reasons, the remaining test cases scheduled for Mach 1.69 were replaced by other testing at lower Mach numbers.

IX

COWL AND SIDE PLATE PRESSURE DRAG

Cowl plus side plate pressure drags are shown on figures 51 thru 55 of Appendix III for configurations R1SP1C1 thru C6 at the five test Mach numbers between 0.69 and 1.39. On the figures, each drag curve has a different zero drag reference. This spreads and separates the data for clarity. The basic drag scale on each figure is applicable to configuration R1SP1C1 only.

At both subsonic and supersonic speeds cowl plus side plate pressure drag is decreased as inlet mass flow ratio is reduced. Additive drag is partially recovered on cowl and side plate lips. At lower mass flow ratios, the drag is negative. These surfaces actually produce thrust. Subsonically and supersonically (0.84 and 1.29 M_o), the drag drops to zero at mass flow ratios as little as 5 or 6 percent below $(A_o/A_c)_{REF}$.

As expected at subsonic speeds the rate of change of cowl plus side plate drag with mass flow ratio is not maximum at maximum mass flow ratio. The drag recovery curves are much like the mathematical reciprocal of the ΔD_{ADD} or $\Delta D_{ADD\ THEORY}$ curve shapes shown on figures 45 thru 46. At Mach 1.29 and 1.39 the reciprocal similarity does not hold between $\Delta D_{ADD\ THEORY}$ and cowl plus side plate drag. Figures 54 and 55 show the rate of change of drag with mass flow ratio to be, generally, maximum at maximum mass flow ratio. Figures 48 and 49 show the $\Delta D_{ADD\ THEORY}$ slope to be minimum at maximum mass flow ratio and show the ΔD_{ADD} slopes to be nearly constant for a wide range of mass flow.

At Mach 0.84, the curved (circular arc) cowl configurations have low drag at high mass flow ratios and low drag with 0.20 A_o/A_c spillage. The straight cowls are definitely second best.

At Mach 1.3, the 10° curved cowl inlet configuration, R1SP1C1, still gives the best performance, but the 6° straight cowl inlet configuration is not too far behind. Of course, at high supersonic speeds, low cowl angles are best.

Cowl selection should be made on the basis of the over-all airplane mission and the relative importance of the critical design points.

X

ADDITIVE DRAG COEFFICIENT, K_{ADD}

Plots of the additive drag coefficient, K_{ADD}, are given in figures 56 thru 94. Coefficients for the following data are presented in order of the indicated nominal Mach number listings[1]:

CONFIG.	α°	β°	Mach Number 0.7	0.85	1.1	1.3	1.4	1.69
R1SP1C1	5	5	x	x	x	x	x	x
R1SP1C2	5	5	x	x	x	x	x	
R1SP1C3	5	5	x	x	x	x	x	
R1SP1C4	5	5	x	x	x	x	x	
R1SP1C5	5	5	x	x	x	x	x	x
R1SP1C6	5	5	x	x	x	x	x	
R1SP1C1	5	9	x	x	x			
R1SP1C1	5	12	x	x	x			
R1SP2C1	5	5	x	x	x	x	x	
R1SP3C1	5	5	x	x	x	x	x	
R1SP1SP3C1	5	5						
R2SP1C1	7	7	x	x		x		
R3SP1C1	12	12	x	x	x	x	x	
R4SP1C1	5	5	x	x	x	x	x	
R4SP4C4	5	5			x	x	x	
R4SP4C6	5	5	x	x	x	x	x	
R4SP4C6	5	9		x	x			
R4SP4C1	5	12		x	x			
R4SP4C6	5	12		x	x			

All curves are faired to the reference mass flow ratio. Because of the large and questionable fairing required for R1SP1C1, $\alpha = 5^{\circ}$, $\beta = 12^{\circ}$, $M_o = 1.09$, the fairing is shown as a dotted extension of the data. For other cases, extensions were shorter and were simply extrapolations of better defined curve shapes. As discussed and illustrated earlier (figures 45 thru 50), fairing to $(A_o/A_c)_{REF}$ generally means a small extrapolation only.

It was pointed out in Section VIII that the ratio $(\Delta D_{ADD})/(\Delta D_{ADD\ THEORY})$ would

1) cause K_{ADD} values to be less than 1.0 at subsonic and transonic speed, and
2) cause maximum values of K_{ADD} to often be greater than 1.0 at Mach 1.3 and 1.4.

The K_{ADD} curves show these effects.

---

1. The configuration R1SP1SP3C1 has two different side plates, an SP1 and an SP3 side plate.

At Mach 1.09 and to a degree at 0.84, the K_{ADD} curves for R1SP1C4 have an unusual relationship with data of other configurations. Examination of the data substantiates this trend. First, the cowl plus side plate drag curve shown on figure 53 for R1SP1C4 at M_o = 1.09 does show a reverse of the usual curvature. These data are independent of the K_{ADD} development, yet they agree. Second, examination of the cowl pressure profiles clearly show a departure from the usual trend. On figure 95, centerline cowl pressure are plotted for both the C3 (10° straight) and C4 (15° straight) cowls. Considering the C3 data to represent the usual pressure profile trend, a clear substantiation for the C4 K_{ADD} data is apparent. The C4 data show that a very large decrease in pressure-area integrated drag occurs between mass flow ratios of 0.68 and 0.58.

At low mass flows both cowls have pressure distributions typical of separation near the leading edge of the cowl. Cowl C3 shows separation even at high mass flow ratios. Cowl C4, at A_o/A_c = 0.68, shows minor separation then re-attachment of the flow. No separation is indicated at A_o/A_c = 0.73 for cowl C4.

The K_{ADD} coefficients for R1SP1C1 thru C6 were conceptually computed as indicated in Section V. However, because only the cowl was changed from configuration to configuration it was possible to eliminate data scatter seen in figures 45 thru 50. ΔN of equation 7 was found by adding the change in integrated cowl plus side plate drag to the ΔD_{ADD} values found from the faired curves of figures 45 thru 50.

$$\Delta N = \Delta D_{ADD} + \begin{bmatrix} \text{Cowl + Side Plate} \\ \text{Numerical Pressure} \\ \text{Drag Integration} \end{bmatrix} - \begin{bmatrix} \text{Cowl + Side Plate} \\ \text{Numerical Pressure} \\ \text{Drag Integration} \end{bmatrix}_{REF}$$

There was very little scatter in the integrated cowl plus side plate drags as shown on figures 51 thru 55, and almost all K_{ADD} errors due to data scatter (inaccuracy) could be eliminated for the six cowl comparisons.

XI

EFFECT OF SIDE PLATE GEOMETRY ON K_{ADD}

Side plate geometry effects on K_{ADD} are shown for five nominal test Mach numbers between 0.7 and 1.4 in figures 96 thru 100. K_{ADD} is shown for configurations R1SP1C1, R1SP2C1, R1SP3C1, $\alpha = \beta = 5^{\circ}$.

At Mach 0.7, side plate geometry has very little effect on inlet drag except for large flow spillages. There, the drag of the extended side plate configuration is larger.

The same general trends are shown at Mach 0.85. The cut-back side plates look best for high spillages, and the extended side plates are considerably worse.

Transonically at Mach 1.1, side spillage becomes very important. High drag will result from spillage with extended side plates. The cut-back side plates are obviously the best if large spillages are necessary.

At the supersonic speeds K_{ADD} comparisons do not give spillage drag comparisons directly since a different $(A_o/A_c)_{REF}$ is used. Over-all propulsion system performance should be evaluated.

XII

RAMP PRESSURE DISTRIBUTIONS

Ramp drag is pertinent to data presented in the following sections of this report. As shown in Appendix I, the initial fixed ramp was instrumented with four static pressure taps, and the variable external ramp was instrumented with twenty-one static pressure taps. Ramp drag coefficients used in data analysis were obtained by mathematical pressure-area integrations based upon these twenty-five measured pressures.

Figures 101 thru 108 show typical subsonic ($M_0 \approx 0.85$) and supersonic ($M_0 \approx 1.3$) ramp centerline pressure distributions for a range of inlet mass flow ratios. Pressure distributions for the following configurations are given at each Mach number:

R1SP1C1, $\alpha = \beta = 5^\circ$
R1SP1C1, $\alpha = 5^\circ, \beta = 12^\circ$
R1SP2C1, $\alpha = \beta = 5^\circ$
R1SP3C1, $\alpha = \beta = 5^\circ$

These configurations illustrate each major flow situation since ramp angle and side plate geometry are the primary geometric variables affecting ramp pressure distribution.

All four subsonic cases show that force is exerted by the ramp in turning the flow from the freestream direction. The R1SP1 and SP2 cases show pressures at the leading edge to be about 1.14 P_0. The extended side plates, R1SP3, create ramp leading edge pressures in the 1.2 P_0 to 1.3 P_0 range, and mass flow changes were clearly felt over the entire ramp length. The R1SP1C1, $\alpha = 5^\circ$, $\beta = 12^\circ$, configuration shows the pressure rise on the second ramp due to the additional turning. All cases show the expected ramp pressure decay after flow turning is accomplished.

Supersonically R1SP1C1, $\alpha = \beta = 5^\circ$, shows the effect of supersonic side spillage in the pressure decay on the ramp aft of the leading edge (figure 105). The change of terminal shock wave position with mass flow ratio can also be seen. Due to boundary layer build-up on the inlet surfaces and slight internal contraction, a true maximum mass flow ratio case with shock-on-cowl was not obtained. The measured maximum was 0.76. Extrapolations of data to $(A_0/A_c)_{REF} = .780$ were used in the analysis.

Figure 106 shows the situation of a detached shock wave caused by the second external ramp of configuration R1SP1C1, $\alpha = 5^\circ$, $\beta = 12^\circ$. Figure 107 shows the ramp pressure distribution with the SP2 cut-back side plates.

Supersonically, configuration R1SP3C1, $\alpha = \beta = 5^\circ$, with the extended side plates produced an unexpected ramp pressure distribution at maximum mass flow ratio. No ramp pressure decay is expected forward of the point where an expansion fan originating at the intersection of initial oblique shock wave and upper limit of the side plate would strike the ramp. No ramp pressure decay is seen in this region, but the pressure decay aft of this point is extremely rapid. The dP/dx in this region is approximately twice as great as the maximum dP/dx for the SP1 triangular side plates and approximately equal to the maximum dP/dx of the SP2 cut-back side plates. Further, the minimum pressure after decay is only 1.03 P_o, even lower than the minimum pressure recorded with the cut-back side plates. As can be seen, the terminal shock wave did reach the cowl lip. This did not happen with the other configurations.

The terminal shock travel distance per unit change in mass flow ratio was largest for the SP3 side plates and smallest for the SP2 side plates as would be expected. The larger the possible subsonic side spillage, the smaller the necessary terminal shock travel for that spillage. From this data it is apparent that a rigorous mathematical model of the inlet flow situation must relate shock travel to side plate geometry.

At $M_o \approx 1.3$, the R1SP2C1 configuration captured the greatest mass flow, and R1SP3C1 captured the least. In general, as seen from the terminal shock wave position, maximum mass flow ratio was determined by inlet choking. The apparent trend is: the more extensive the side plates, the more the boundary layer build-up and the smaller the maximum mass flow ratio.

XIII

SYNTHESIZING TOTAL INLET DRAG

To select the proper inlet configuration for an airplane, the evaluation of

$$(F_{INT})_{COR} = F_N - K_{ADD}(\Delta D_{ADD\ THEORY}) \qquad \text{Eq. (13)}$$

is not enough. The total drag chargeable to the inlet must be evaluated and compared. This is

$$D_{TOTAL} = K_{ADD}(\Delta D_{ADD\ THEORY}) + (D_{ADD})_{REF} + \begin{pmatrix} \text{Cowl + Side Plate} \\ \text{Pressure Drag} \end{pmatrix}_{REF} \qquad \text{Eq. (14)}$$

It is proposed that the user obtain D_{TOTAL} from a synthesis of measured data and theoretical calculations. The quantity $K_{ADD}(\Delta D_{ADD\ THEORY})$ can be estimated from information already presented. The quantity

$$\begin{pmatrix} \text{Cowl + Side Plate} \\ \text{Pressure Drag} \end{pmatrix}_{REF}$$

can be estimated from figures 51 thru 55 for the user's calculated value of $(A_o/A_c)_{REF}$.

It is proposed that the final quantity for equation 14, $(D_{ADD})_{REF}$, be evaluated by using the methods of the mathematical flow models of Appendix II -- with one exception. The exception is that ramp drag at the reference mass flow ratio, $(D_R)_{REF}$, be evaluated on an empirical rather than a theoretical basis. Section XIV presents the empirical basis for $(D_R)_{REF}$.

XIV

RAMP DRAG AT $(A_o/A_c)_{REF}$

Reference 11 presents a compilation of theory and experimental data on transonic flow over two-dimensional wedges from the work of J. D. Cole, H. S. Tsien, J. Baron, W. G. Vincenti and G. Gunderly. The compilation, illustrated in figure 9, is presented in the form of "reduced drag coefficient" and "reduced Mach number", both of which are functions of wedge thickness to chord ratio (t/c). In the "reduced" form, data from many wedges can be coalesced or normalized into the single curve of figure 9. A great deal of original test data from reference 11 supports the validity of this single wedge drag curve.

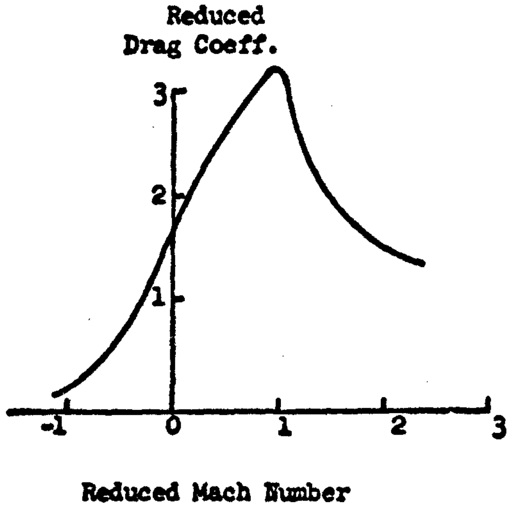


Figure 9. Wedge Drag

A similar normalization of reference ramp drag, $(D_R)_{REF}$, has been attempted. It is understood that complete data coalescence can not be expected because of inlet side spillage effects, particularly above $M_o = 1.0$. Ramp drags for both single ramp ($\alpha = \beta$) and double ramp ($\alpha \neq \beta$) inlets are included by defining thickness and chord as shown in figure 10.

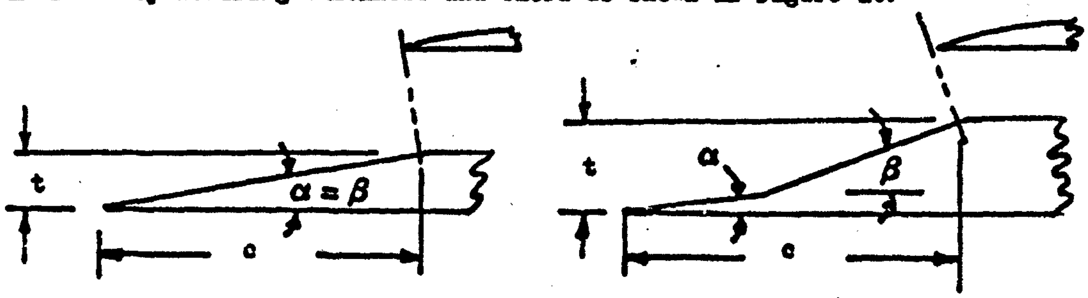
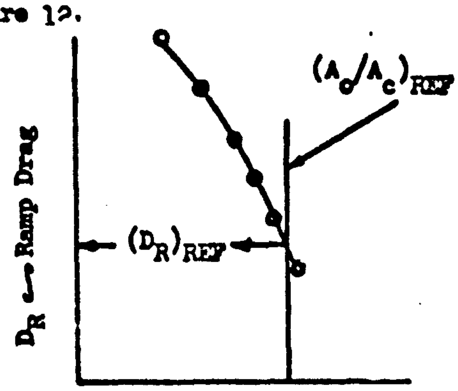
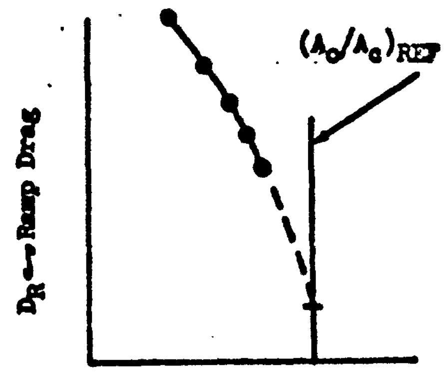


Figure 10. Inlet Ramp Thickness and Chord

For the tested configurations, if measured maximum mass flow ratio exceeded $(A_o/A_c)_{REF}$, $(D_R)_{REF}$ was obtained by the straightforward process illustrated in figure 11. However, inlet choking caused by internal contraction and boundary layer build-up normally limited the maximum $(A_o/A_c) > (A_o/A_c)_{REF}$ situation to the Mach 0.7 test data. Thus, at higher Mach numbers, extrapolations of the ramp drag data were required, also, as illustrated in figure 12.





A_o/A_c ⟷ Inlet Mass Flow Ratio

Figure 11. Ramp Drag where Max. $A_o/A_c > (A_o/A_c)_{REF}$

Figure 12. Ramp Drag where Max $A_o/A_c < (A_o/A_c)_{REF}$

Several restrictions were placed upon the allowable extent of extrapolation to insure against extrapolating to drag levels below the physically obtainable minimum. Two restrictions were imposed:

Restriction 1) For the subsonic and supersonic detached shock wave cases, D_R was not extrapolated beyond the value at which corresponding ramp pressure extrapolations showed sonic flow on the ramp at the cowl lip station.

Restriction 2) For attached shock supersonic cases, D_R was not extrapolated below the value corresponding to the terminal shock wave at the cowl lip as determined by ramp pressure profile analysis.

Both restrictions are given more detailed treatment below. Restriction 2) requires the least discussion and is covered first.

Restriction 2) was applied to only two cases used in the $(D_R)_{REF}$ summary, R1SP3C1 at $M_o = 1.3$ and at $M_o = 1.4$. Figure 108 illustrates the ramp pressure profile for the Mach 1.3 case. The terminal shock wave was obviously at the cowl lip at the maximum measured mass flow ratio. The Supersonic Mathematical Model of Appendix II accounted for no side spillage and gave an $(A_o/A_c)_{REF}$ larger than the measured maximum. For these two cases the integrated ramp pressure drag at the maximum measured mass flow ratio was used for $(D_R)_{REF}$. For the remaining attached shock cases, $(D_R)_{REF}$ was taken as the extrapolated value of D_R at $(A_o/A_c)_{REF}$.

Restriction 1) is based upon a hypothesis of the effect on ramp drag of the presence or absence of boundary layer. Certainly there is no question of the validity of ramp drag extrapolation to account for internal contraction in the inlet, but what of extrapolation beyond the point where local Mach number would become sonic on the ramp at the cowl lip station as illustrated in figure 13?

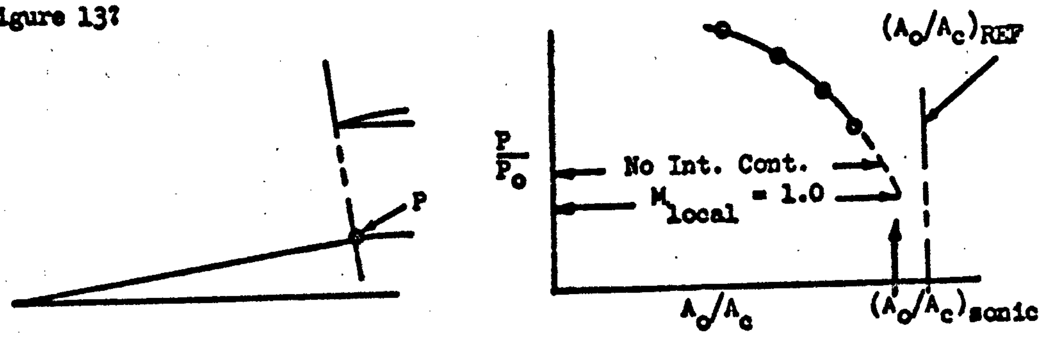


Figure 13. Sonic Flow at Inlet Lip

The figure shows a typical variation of measured pressure at the lip station vs. (A_o/A_c) found during testing at $M_o \approx 0.85$ and supersonically for detached shock wave cases. Before the extrapolation reaches $(A_o/A_c)_{REF}$, pressures which would cause local sonic flow on the ramp are encountered. Elimination of boundary layer would not allow extrapolation to $(A_o/A_c)_{REF}$, but it would allow the (P/P_o) vs. (A_o/A_c) curve to shift to the right until it intersects the $(A_o/A_c)_{REF}$ line properly at or above the sonic pressure ratio.

It is hypothesized that the ramp pressure distribution, hence minimum ramp drag, will be essentially the same when sonic flow is encountered at the lip station regardless of the presence or absence of small amounts of boundary layer.

Using this hypothesis, then, for all subsonic and supersonic detached shock cases, $(D_R)_{REF}$ was taken as the higher of the two following values:

1) the ramp drag at $(A_o/A_c)_{REF}$,
2) the ramp drag at which local sonic flow would occur on the ramp at the cowl lip station.

A summary of $(D_R)_{REF}$ values obtained is given on figure 109 along with the two-dimensional wedge drag curve of reference 11. As noted on the figure, planform ramp area is used as the ramp reference area rather than projected frontal area in order to allow direct comparison to the wedge drag curve of reference 11. In all other portions of this report, A_R refers to ramp projected frontal area.

In figure 109 the subsonic $(D_R)_{REF}$ points are the symbols in the negative region of reduced Mach number. Regardless of side plate or ramp geometry or test Mach number, these data coalesced excellently. These subsonic reference drags, particularly those at Mach 0.7, lie above the wedge drag curve as should be expected. Wedge flow corresponds to higher values of $(A_o/A_c)_{REF}$ than have been assigned to the inlets.

It can be seen that $(D_R)_{REF}$ is not zero subsonically as is predicted by the mathematical models of Appendix II. For this reason an empirical rather than a theoretical value of ramp drag has been suggested for calculating D_{TOTAL} of equation 14.

The solid symbols on figure 109 represent inlet operation at supersonic speeds with a shock wave detached from the initial inlet ramp. All data except the Mach 1.3 and 1.4 cases of R3SP1C1 show reasonable coalesence, especially since data separation due to side spillage is to be expected supersonically. It is apparent that side spillage causes the reference ramp drag values to fall well below the two-dimensional wedge drags.

The five flagged symbols represent two-ramp inlet operation ($\alpha \neq \beta$) where an oblique shock wave is attached at the initial ramp and a detached shock wave stands just forward of the second ramp. The mathematical models of Appendix II were not designed to compute a reference mass flow ratio for these cases. Therefore, these five points are shown for the maximum measured mass flow ratio. Because tunnel flow was slightly misaligned at Mach 1.3 and 1.4 and because on a comparable $(A_o/A_c)_{REF}$ basis these drags should be somewhat lower, it is suggested that $(D_R)_{REF}$ values for similar inlet operation be selected at the lower limit of the "primary range of data" shown on the figure.

The open symbols (unflagged) at the right of figure 109 denote $(D_R)_{REF}$ values for the supersonic flow case where an oblique shock wave is attached at the initial inlet wedge and $\alpha = \beta$. Except for the R1SP3C1 cases, ramp drags were extrapolated to $(A_o/A_c)_{REF}$ to find $(D_R)_{REF}$. Analysis of the ramp pressure profiles for these cases showed that the computed $(A_o/A_c)_{REF}$ values were too small to correspond to shock-on-cowl operation.

It is proposed that reference ramp drags, $(D_R)_{REF}$, be selected from the "primary range of data" of figure 109.

As a first attempt, ramp drag normalization has been very successful subsonically and reasonably successful supersonically. A means of unification of ramp drag data for performance prediction seems to be almost a necessity considering the geometric variations from inlet to inlet. The reduced drag vs. reduced Mach number presentation of figure 109 appears to offer a reasonable approach. More sophisticated mathematical flow models for $(A_o/A_c)_{REF}$ predictions, especially at the higher supersonic speeds, are a desirable refinement of this approach.

XV

SPILLAGE DRAG COMPARISON - R1SP1C1 THRU R1SP1C6

The chargeable inlet spillage drag, D_{TOTAL}, is given in coefficient form for configurations R1SP1C1 thru C6 at Mach 0.84 and 1.29 in figures 110 and 111 of Appendix III. D_{TOTAL} in equation 14 was defined as

$$D_{TOTAL} = K_{ADD} \left(\Delta D_{ADD\ THEORY} \right) + \left(D_{ADD} \right)_{REF}$$

$$+ \begin{pmatrix} \text{Cowl + Side Plate} \\ \text{Pressure Drag} \end{pmatrix}_{REF} = D_{ADD} + \left[\int (P-P_o) dA \right]_{\text{Cowl + Side Plate}}$$

and its evaluation was explained. Evaluation of D_{TOTAL} from actual experimental data, as in this case, is more direct. Consideration of equations and 14 shows that

$$D_{TOTAL} = \left[D_{ADD} - (D_{ADD})_{REF} \right] + \left[\int (P-P_o) dA \right]_{\substack{\text{Cowl +} \\ \text{Side plate}}} + (D_{ADD})_{REF} \qquad \text{Eq. (15)}$$

The first term was obtained directly from figures 45 thru 50, the second term from figures 51 thru 55. The term $(D_{ADD})_{REF}$ was evaluated as discussed in Sections XIII and XIV.

As can be seen from the figures, the circular arc cowls are best subsonically. The three straight cowls are definitely second best. Supersoncially at Mach 1.29, the C1 10° circular arc cowl and the 6° straight cowl, C2, were best and quite comparable. At high supersonic speeds low angle cowls are, of course, best.

The thick cowl, C6, had low drag both subsonically and supersonically at Mach 1.3 for very large spillages. However, at high supersonic Mach numbers the drag of C6 is expected to be large.

XVI

SPILLAGE DRAG OF VARYING RAMP OR COWL

Measured external model drag coefficients vs. mass flow ratio are given for configurations

R1SP1C1; $\alpha = 5^\circ$, $\beta = 5^\circ$
R1SP1C1; $\alpha = 5^\circ$, $\beta = 9^\circ$
R1SP1C1; $\alpha = 5^\circ$, $\beta = 12^\circ$

R1SP1C1, $\alpha = \beta = 5^\circ$
R1SP1C9, $\alpha = \beta = 5^\circ$
R1SP1C10, $\alpha = \beta = 5^\circ$

for Mach 0.85, 1.1 and 1.3 in figures 112 thru 114 of Appendix III. The upper parts of these figures illustrate the effect of increasing the variable ramp angle. The lower curves show the effect of varying the cowl.

On the abscissa axis of the figures, the captured airflow, A_o, is ratioed to the capture area of the R1SP1C1 configuration. This was done because of the changing inlet capture area involved in varying the cowl. Using a fixed A_c in the A_o/A_c ratio allows direct comparison of spillage drag by varying the ramp angle and by varying the cowl.

The ordinate axis show measured model drag as defined by equation Thus, the ordinate axis drags are

$$D_{ADD} + \left[\int (P - P_o)\, dA \right]_{\substack{\text{Cowl +} \\ \text{Side Plate}}} + (\text{CONST.}) = N$$

and contain a constant drag value pertaining only to the model, not to an aircraft propulsion system.

The chargeable inlet drag at $(A_o/A_c)_{REF}$ for R1SP1C1, $\alpha = \beta = 5^\circ$,

$$(D_{ADD})_{REF} + \left(\begin{array}{c} \text{Cowl + Side Plate} \\ \text{Pressure Drag} \end{array} \right)_{REF} = (D)_{REF}\ {}_{\text{R1SP1C1},\ \alpha = \beta = 5^\circ}$$

as defined in equation 14 is indicated on each figure. Then, the chargeable drag for any configurations becomes

$$D_{TOTAL} = D_{ADD} + \left[\int (P - P_o)\, dA \right]_{\substack{\text{Cowl +} \\ \text{Side Plate}}} \qquad \text{Eq. (16)}$$

$$= N - \left[N_{REF} - (D)_{REF} \right]_{\substack{\text{R1SP1C1} \\ \alpha = \beta = 5^\circ}}$$

For example on figure 112 D_{TOTAL} of R1SP1C10 at Mach 0.85 becomes

$$\frac{D_{TOTAL}}{q_o A_c} = \frac{N}{q_o A_c} - (.2060 - .0254)$$

$$= \frac{N}{q_o A_c} - (.1806)$$

where A_c, again, is the capture area of R1SP1C1.

As can be seen from the data of figures 112 thru 114 both increasing the ramp angle and varying the cowl reduce spillage drag. For the particular model geometries tested and for anticipated spillages, ramp variation showed lower spillage drags than cowl variations. A minimum drag configuration could be obtained by using the combination of ramp and cowl variation. Most supersonic aircraft must have a variable ramp. A variable cowl would be an addition. The variable cowl weight penalty must be traded against lower spillage drag before a variable cowl can be justified.

XVII

SPILLAGE DRAG, SHARP vs. BLUNT COWL LIPS

Several blunted lip cowls were tested for possible application in hypersonic inlets. Figure 115 shows a comparison of the external drags of configurations R1SP1C1, C7 and C8 at Mach 0.85 and 1.29. The abscissa and ordinate axes of the figure and the "zero drag reference" of a similar presentation were explained in detail in the preceeding section. Again, drag is shown ratioed to the capture area, A_c, of configuration R1SP1C1.

Cowl C1 had a sharp lip. Cowls C7 and C8 had lip radii of 0.04" and 0.1", respectively. At 0.85 Mach the drags of R1SP1C1 and C7 are very comparable. The small drag difference at the high mass flow end of the plot may, in part, be due to data scatter. The larger lip radius on R1SP1C8 did cause a drag penalty.

At Mach 1.29, configuration drag was very definitely a function of lip bluntness. The smaller the lip radius, the smaller the drag.

XVIII

CONCLUSIONS AND RECOMMENDATIONS

1. When transonic inlet performance is considered in inlet selection, the total chargeable drag of the various inlet configurations should be evaluated. Though a given inlet may achieve a high degree of additive drag cancellation, the total drag of that inlet may eliminate it from consideration.

2. Lower spillage drags were obtained by using rotation of the variable external ramp of the inlet to deflect excess airflow than by using inward rotation of a variable cowl to spill air. Since a variable second external ramp is normally required on supersonic rectangular inlets, there is no additional weight penalty involved in using the variable ramp to obtain lower transonic spillage drags.

3. The combination of variable cowl and variable ramp should achieve lower spillage drag than the ramp alone. However, the transonic spillage drag decrease must be traded-off against variable cowl weight penalties.

4. Blunting the leading edge of the 10° circular arc cowl had little effect upon additive drag cancellation, and edge blunting did increase total chargeable inlet drag. If lip blunting is required for take-off performance increases, for anti-icing or for heat-transfer or structural reasons, the blunting penalties at transonic speeds can be estimated from data included in this report.

5. Circular arc cowls with 10° and 15° initial angle showed lower drag than the 6°, 10° and 15° straight cowls at Mach 0.85, both at the reference mass flow ratio and 0.20 A_o/A_c lower. Supersonically at Mach 1.3, the 10° circular arc cowl was still best, but the 6° straight cowl was a very close second. Of course, at high supersonic speeds low cowl angles are desirable.

6. Mathematical models for the computation of theoretical additive drag have been devised. The models were deliberately simplified to make hand calculations practical. Because of the large number of such calculations involved in test data analysis a computer program was written and is included. In addition, additive drag correction factors, K_{ADD}, were determined for a number of inlet configurations from experimental data. By using K_{ADD} and $\Delta D_{ADD\ THEORY}$ which is obtainable from the mathematical models, the drag for airflow spillage below the reference mass flow ratio can be determined.

7. Ramp pressure drags at the reference mass flow ratio for transonic speeds have been normalized and compared with wedge drag theory developed in reference 11. These data provide useful empirical information. Cowl plus side plate drags for a number of configurations have also been determined. The empirical ramp drag and cowl plus side plate drag (at the reference mass flow ratio) can be used to compute total inlet drag at the reference mass flow ratio.

8. Total chargeable inlet drag at any mass flow can be found by summing K_{ADD} ($\Delta D_{ADD\ THEORY}$) from item (6) and total drag at the reference mass flow ratio as discussed in item (7). It is recommended that care be taken in selecting K_{ADD} and the cowl plus side plate drag. Cowl shape was found to be very important in spillage drag.

APPENDIX I

WIND TUNNEL MODEL DESCRIPTION

1. General. The model description within this appendix includes all information needed for comprehension of the reported data. A detailed description of the model, model construction drawings and a description of the on-test-site data reduction equations are available in references 12 or 13.

2. Over-all Arrangement. Figure 14 illustrates the force model assembly. In general, only components of aerodynamic interest are shown. Basically, the inlet is categorized as
   a) supersonic,
   b) rectangular,
   c) external ramp type.

Interchangeable cowls, side plates and fixed initial ramps were constructed for the model and tested. Variable ramps were attached to the aft end of the fixed initial ramp. The ramp train consisted of the fixed initial ramp (interchangeable), a second external ramp, an internal throat panel and an aft panel. The three variable panels were remotely actuatable from the wind tunnel control room, allowing the second external ramp to be adjusted thru an angular range of 5° to 12° with respect to the free stream vector.

The ramp train was connected together by rotating "piano" hinges. For each interchangeable ramp installation, the forward hinge axis of the variable external ramp was fixed. Power linkage of the parallelogram type was attached to the throat panel only. Thus, all throat panel locations could be described by a series of translations of the panel along and perpendicular to the fixed longitudinal axis of the model. A sliding hinge at the aft end of the last panel in the ramp train allowed the end of that panel to slide back and forth along the subsonic diffuser wall.

To simplify drag measurements neither the ramp train nor any other surface of the model had boundary layer removal provisions. Since boundary layer was not bled off, care was taken to eliminate the possibility of flow separations in the forward portion of the inlet caused by jets of high pressure air fed into the duct from beneath the ramp train. "Teflon" strips were inserted into the edges of the external ramp and the throat panel. This created a tight, though sliding, seal between ramps and duct walls. The "piano" hinges at the juncture of the external ramps and at both ends of the throat panel were entirely encased in hardened liquid rubber. The rubber, though filling all joints of the hinges, was sufficiently elastic to allow the necessary minor rotations of the ramps.

At the juncture of the "live" and "dead" portions of the force model a labyrinth seal was installed which virtually eliminated flow leakage, Though small, the leakage flow was calculated from measured pressures across the seal using seal calibration curves. All data were corrected for seal leakage. "Live" section exit conditions (total and static pressures) were measured by total head rakes, static rakes and wall static taps. Flow straigtening screens were installed forward of the "live" section exit to improve the exit velocity profile.

The "live" and "dead" portions of the model were attached thru a 2 1/2 inch diameter Task Mark III-40037 six component force balance (280 lb. rated chord force) supplied by NASA Ames. All pressure taps located on the "live" section of the model were read out thru NASA Ames supplied "Scannivalves" located on the "live" section. This eliminated the need for jumpering flexible pressure tubes between "live" and "dead" model portions, which could have caused force measurement errors.

A large aerodynamic shield was fixed to the forward end of the "dead" section of the model. The shield projected forward over a considerable portion of the "live" section. Not only did the shield surround the balance and "Scannivalves", but it surrounded all portions of the "live" section of the model where unwanted changes in pressure drag (as a function of inlet mass flow ratio) might occur from flow spillage over the cowl and around the side plates.

The initial portion of the "dead" section consisted of a diffusing pipe and a long section of flow straightening pipe ahead of the flow metering nozzle. Four different metering nozzles had been constructed to assure proper meter size for various test conditions. Most "dead" section pressures were read out thru "Scannivalves" located on the "dead" section. The metering nozzle pressure instrumentation, however, was routed outside the tunnel and read on high accuracy equipment to assure valid mass flow data.

A remotely actuatable throttling plug located at the end of the model was used for inlet mass flow control.

The entire model assembly was cantilevered from the vertical tunnel strut, and the model longitudinal axis was fixed at 0^{o} angle of attack, 0^{o} angle of yaw for the entire wind tunnel test.

3. Interchangeable Components. Several different initial ramps, sets of side plates and inlet cowls were constructed. The model was such that many ramp, side plate and cowl combinations could be assembled and tested. Figure 15 illustrates the assembly R1SP1C1, combining initial ramp R1, side plate set SP1 and cowl C1.

In all, four initial ramps, four sets of side plates and ten cowls were constructed. Ramps R1 thru R4 are described in figure 16, side plates SP1 thru SP4 in figure 17, and cowls C1 thru C10 in figures 18 thru 20. The following combinations were tested:

R1SP1C1	R1SP1C7	R1SP1SP3C1
R1SP1C2	R1SP1C8	R2SP1C1
R1SP1C3	R1SP1C9	R3SP1C1
R1SP1C4	R1SP1C10	R4SP4C1
R1SP1C5	R1SP2C1	R4SP4C4
R1SP1C6	R1SP3C1	R4SP4C6

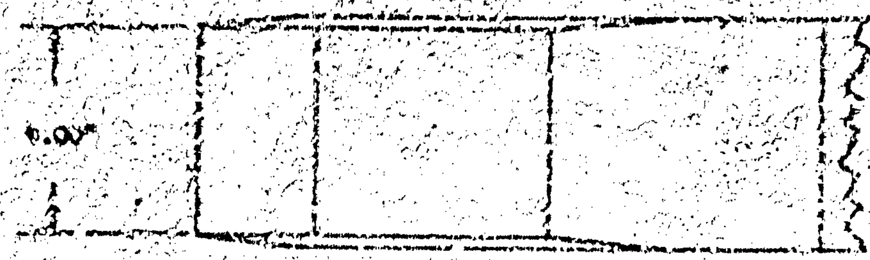
The R1SP1 ramp-side plate combination represents a shock-on-cowl Mach 3.0 inlet. R1SP1C1 thru C6, then, emphasize cowl shape variations. The R1SP1C7 and C8 assemblies were blunted leading edge (hypersonic) configurations. The R1SP1C9 and C10 configurations, together with the basic R1SP1C1, simulated hinged cowl operation.

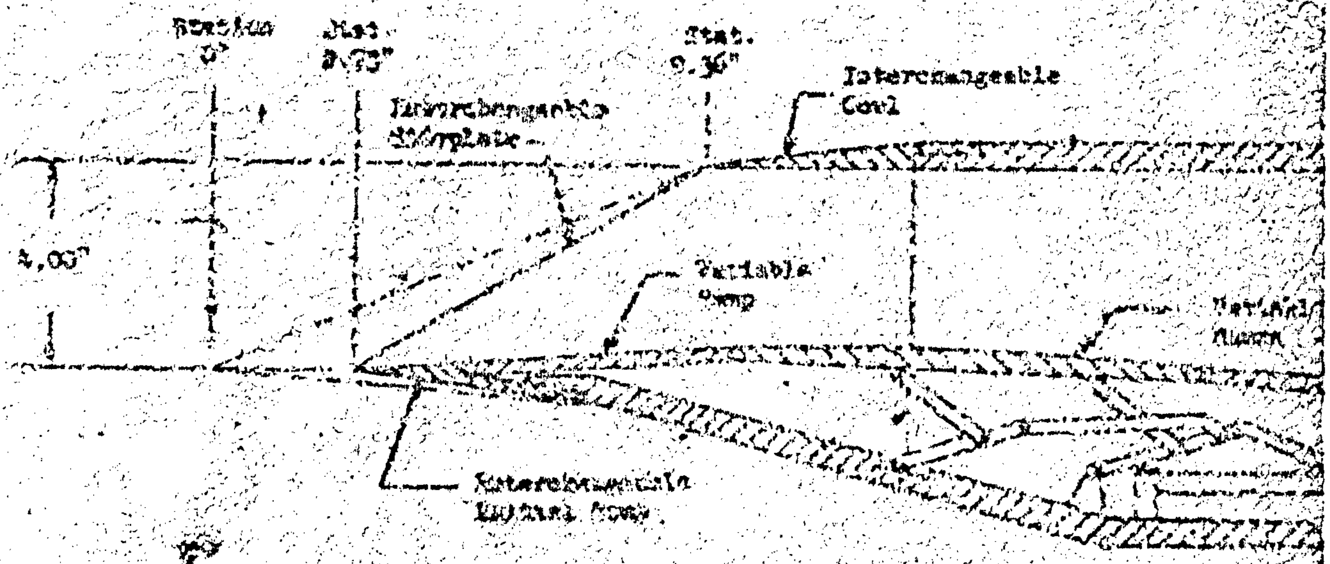
Combinations R1SP1C1, R1SP2C1, R1SP3C1 and R1SP1SP3C1 have side plate (side spillage) area differences. Initial ramp angle changes are brought out by the R1SP1C1, R2SP1C1 and R3SP1C1 assemblies.

The R4SP4C1, C4 and C6 series is a Mach 2.2 shock-on-cowl inlet with three cowl shape variations.

4. Pressure Instrumentation. Ramps R1 thru R4 were each instrumented with four static pressure taps (Figure 21). Twenty-one static pressures were recorded on the external variable ramp (Figure 22). Cowls C1 thru C10 were each instrumented with ten pressure taps (Figure 23). Only side plates SP1 and SP3 were instrumented (Figure 24).

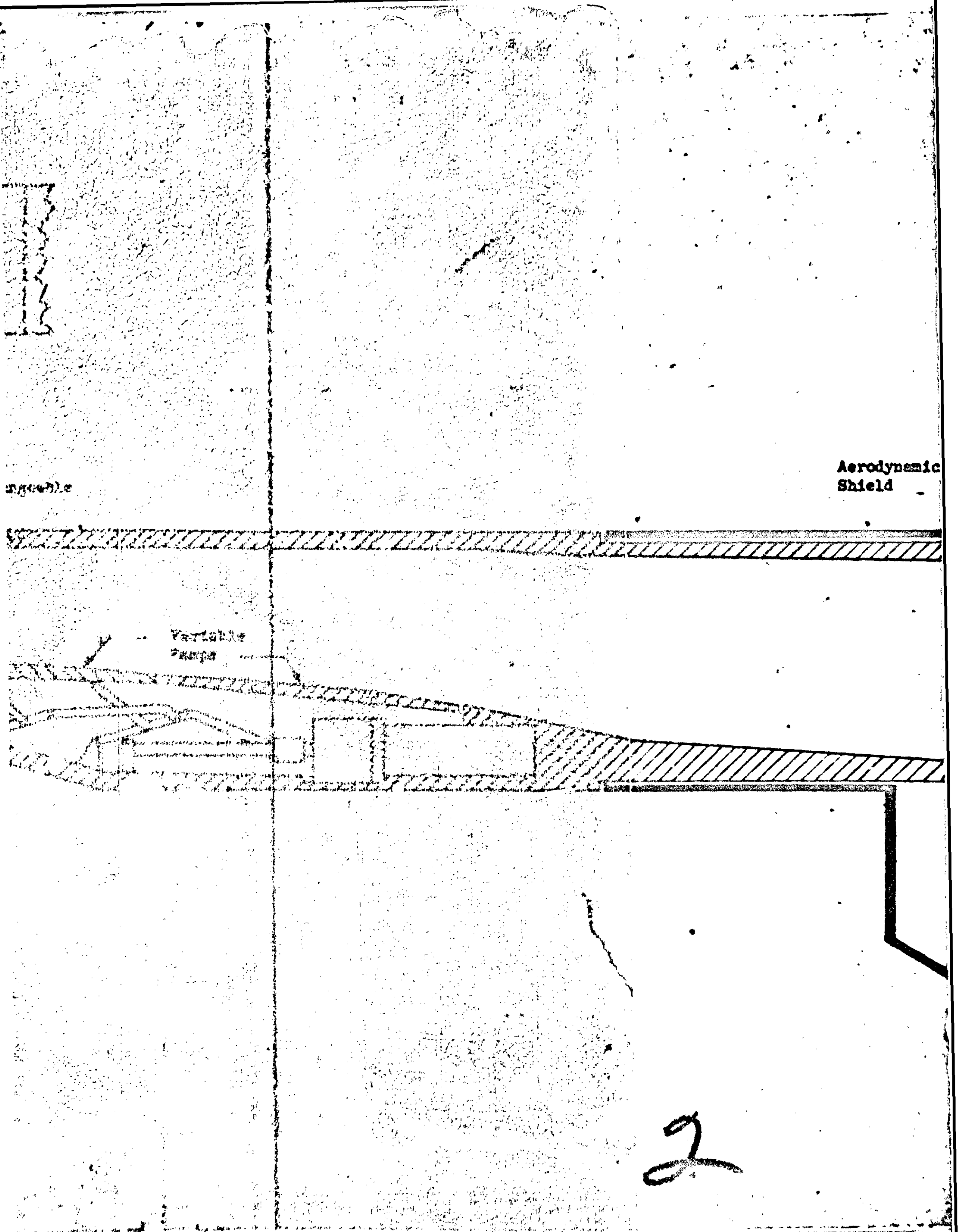
Ramp, side plate and cowl pressures have the prominent part in reported data. Although many other model pressures were recorded and used in data reduction, they are not illustrated or listed. References 12 or 13 give complete instrumentation details.



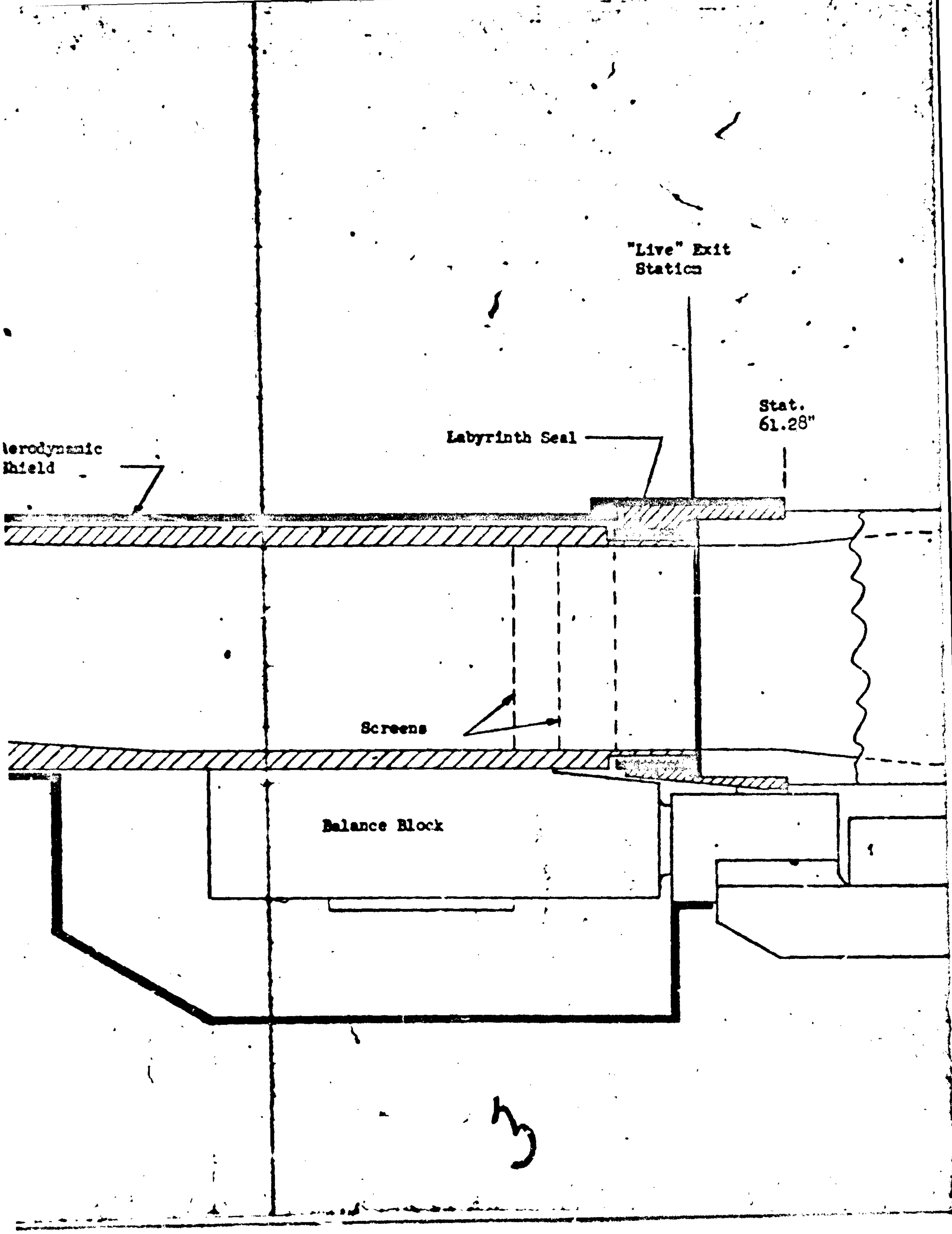


Station 0" [illegible] Model leading edge with initial ramp R1, R2 or R3 installed.

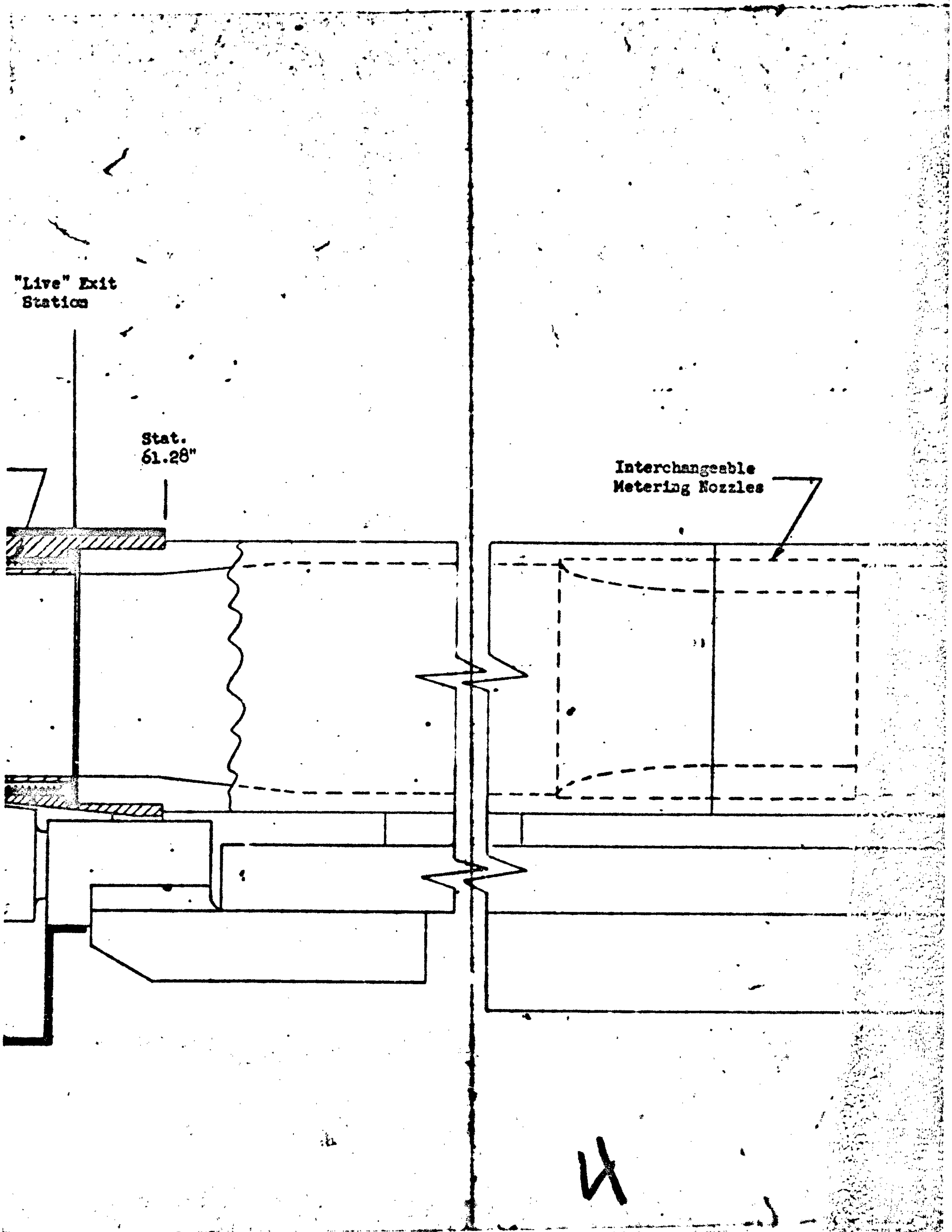
Station 2.72" – Model leading edge with ramp R4 installed.



2



"Live" Exit
Station
Stat.
61.28"
Labyrinth Seal
erodynamic
Shield
Screens
Balance Block


"Live" Exit Station
Stat. 61.28"
Interchangeable Metering Nozzles
4

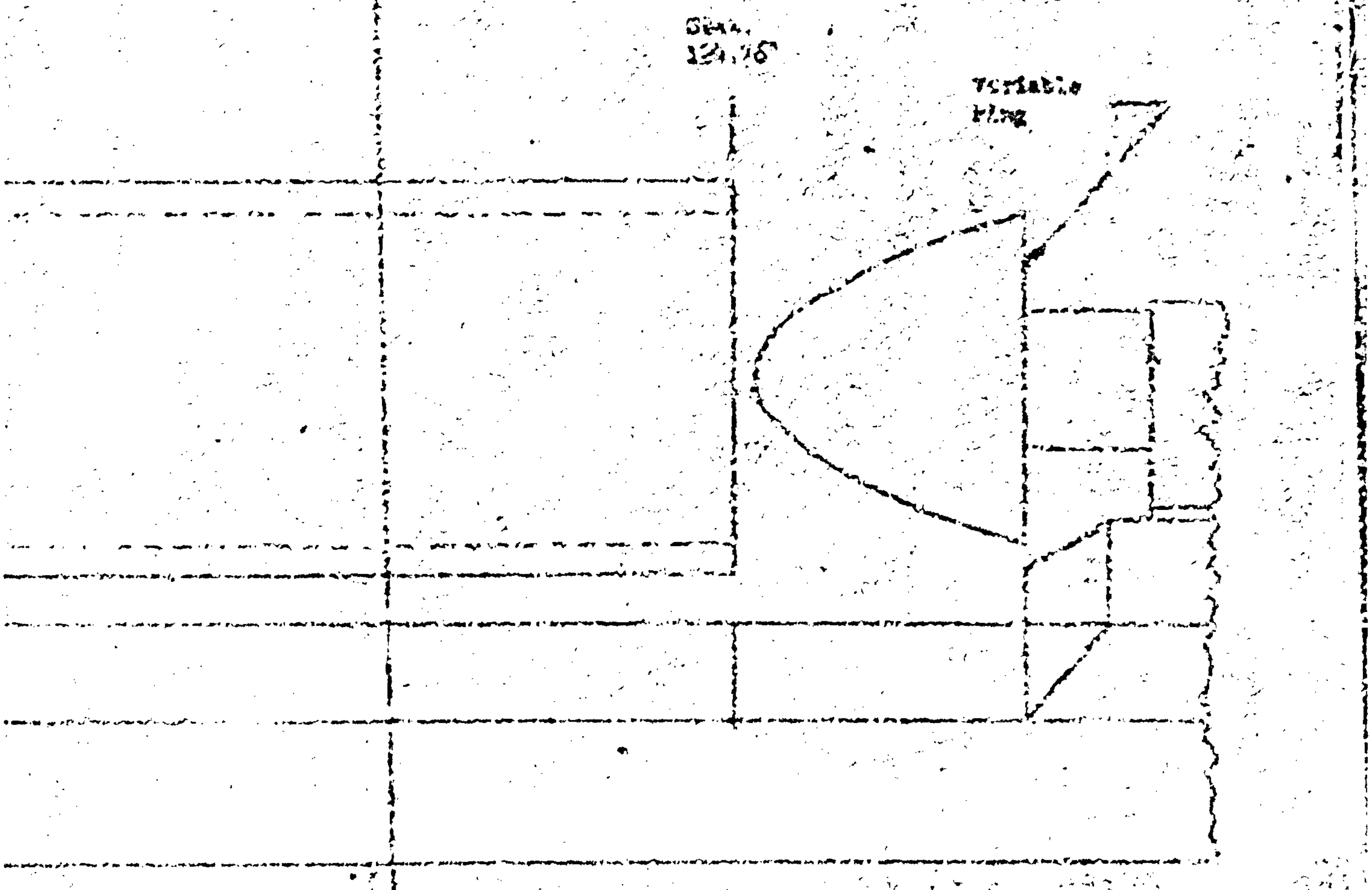
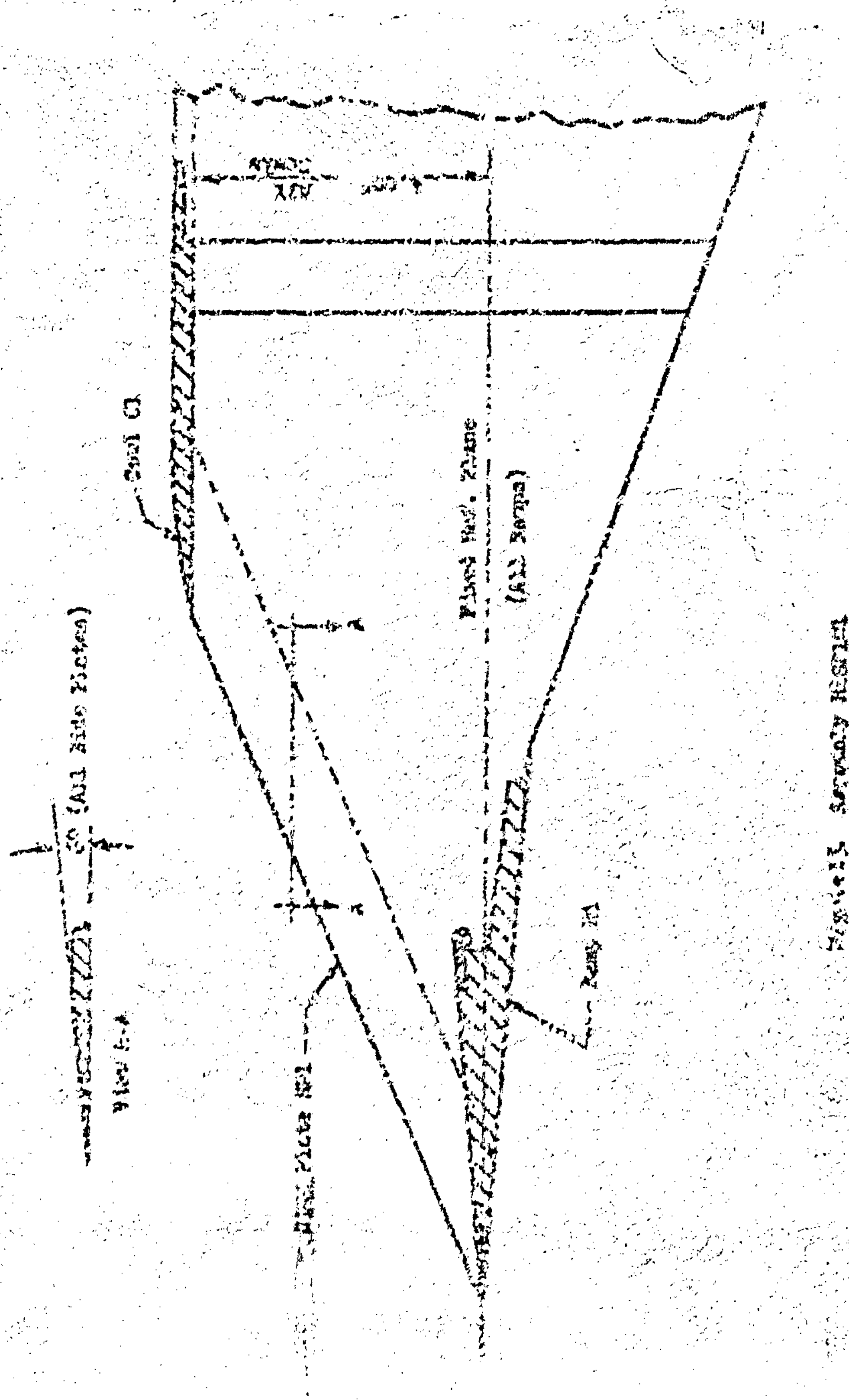
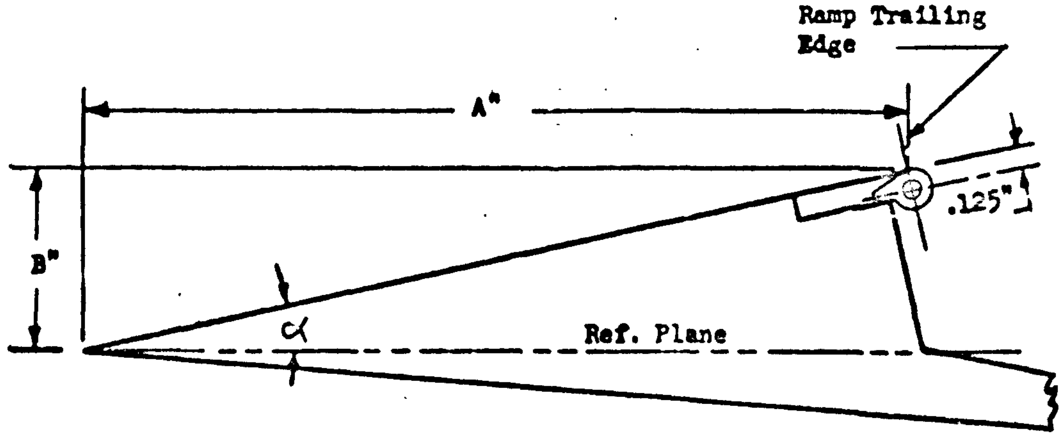
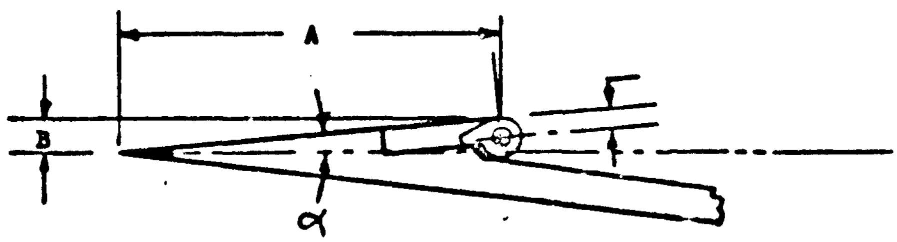


Figure 14, Model Assembly





Ramp	A	B	α
R1	4.959	0.434	5°
R2	4.930	0.605	7°
R3	4.853	1.032	12°



Ramp	A	B	α
R4	2.255	0.197	5°

Figure 16 Ramps R1 Thru R4

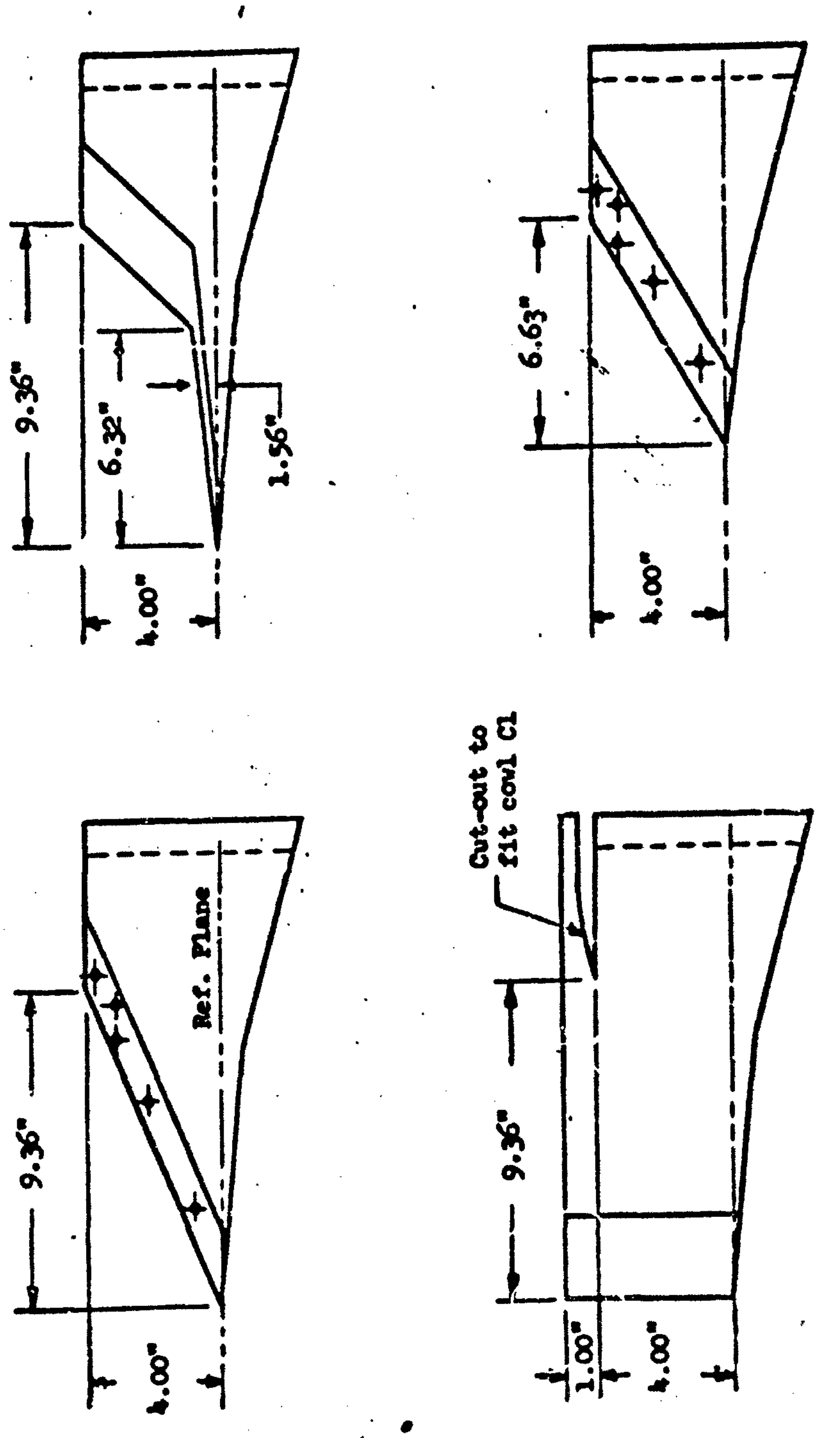
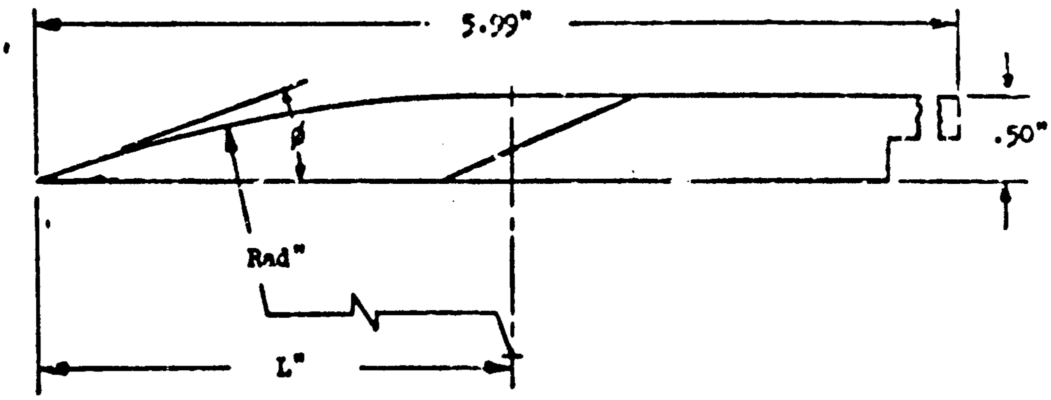
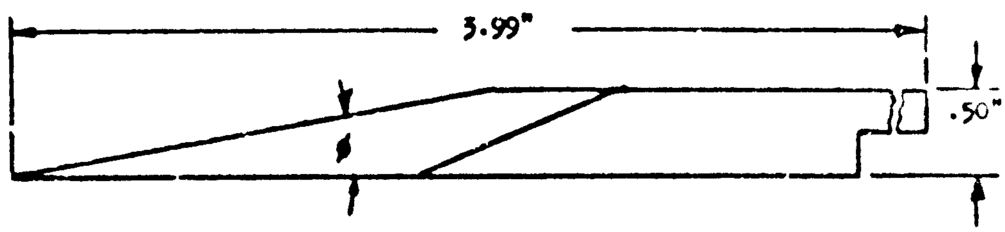


Figure 17. Side Plates SP1 Thru SP4

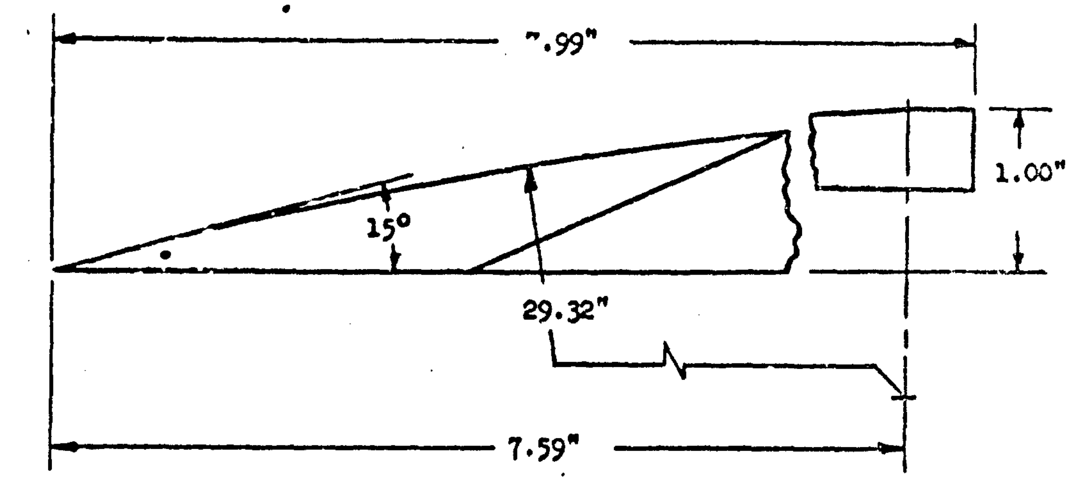


Cowl	L	Rad"	ø
C1	5.71	32.89	10°
C5	3.79	14.66	15°

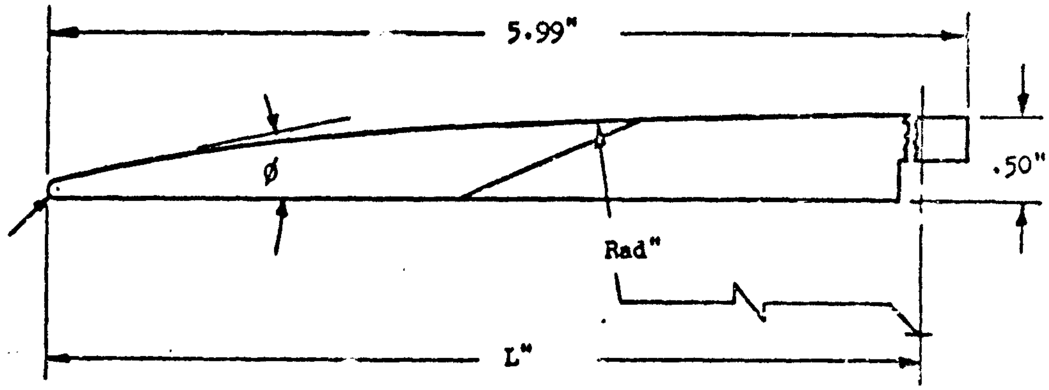


Cowl	ø
C2	6°
C3	10°
C4	15°

Figure 18. Cowls C1 Thru C5

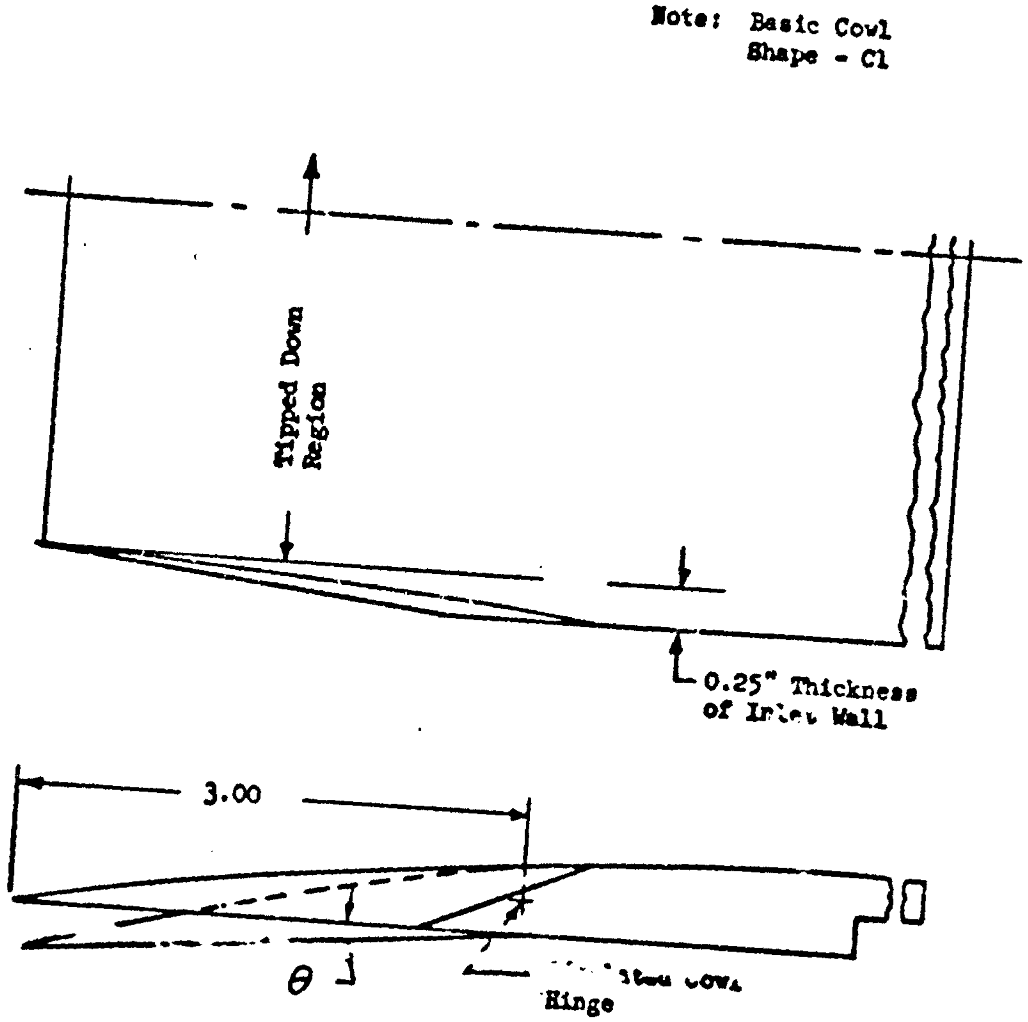


Cowl C6



Cowl	L	Rad"	ø	τ
C7	5.71	32.89	10°	.040
C8	5.71	32.89	10°	.100

Figure 19. Cowls C6, C7, C8



Cowl	θ
C9	5°
C10	10°

Figure 20. Cowls C9, C10

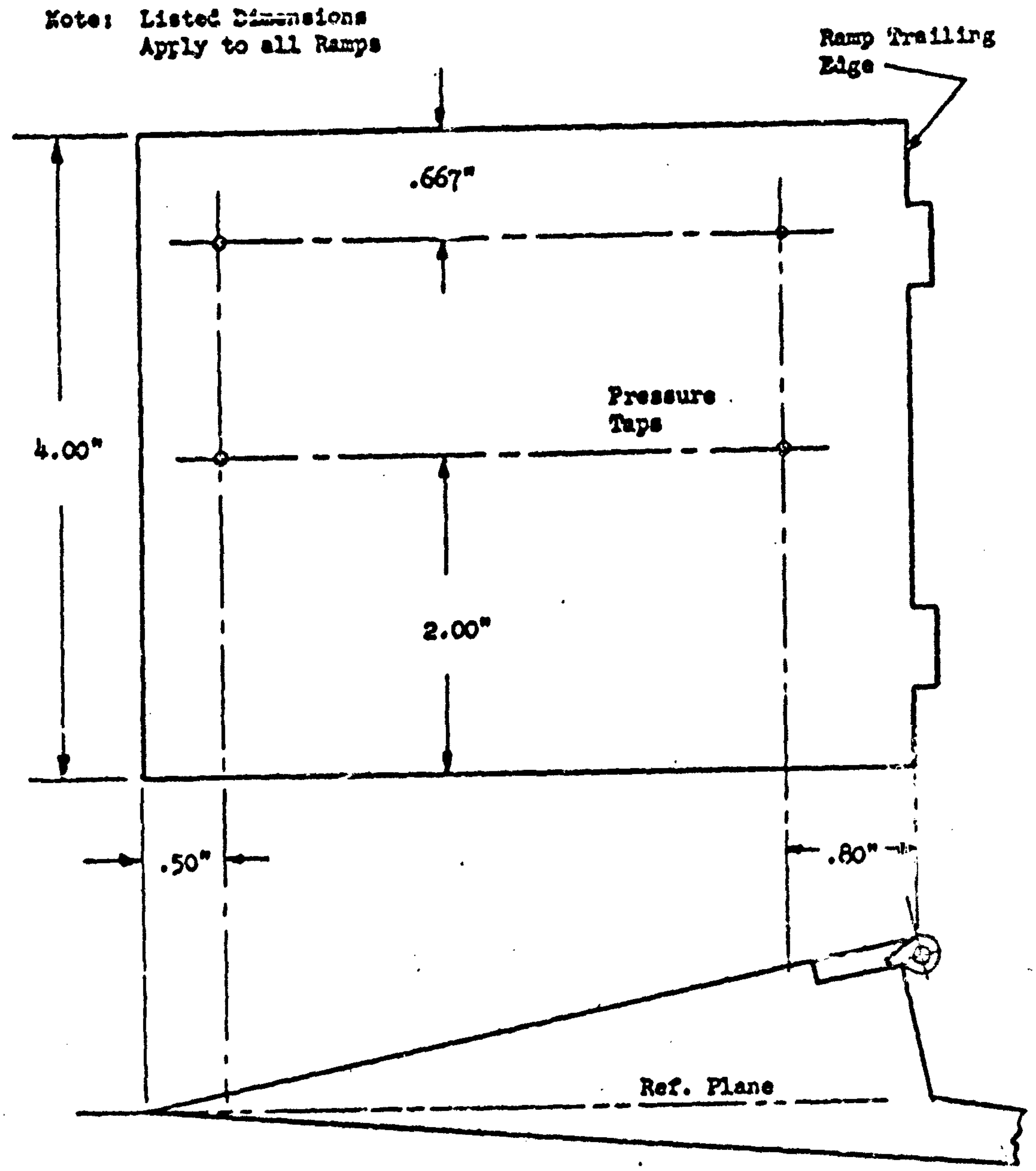


Figure 21. Ramp Pressures

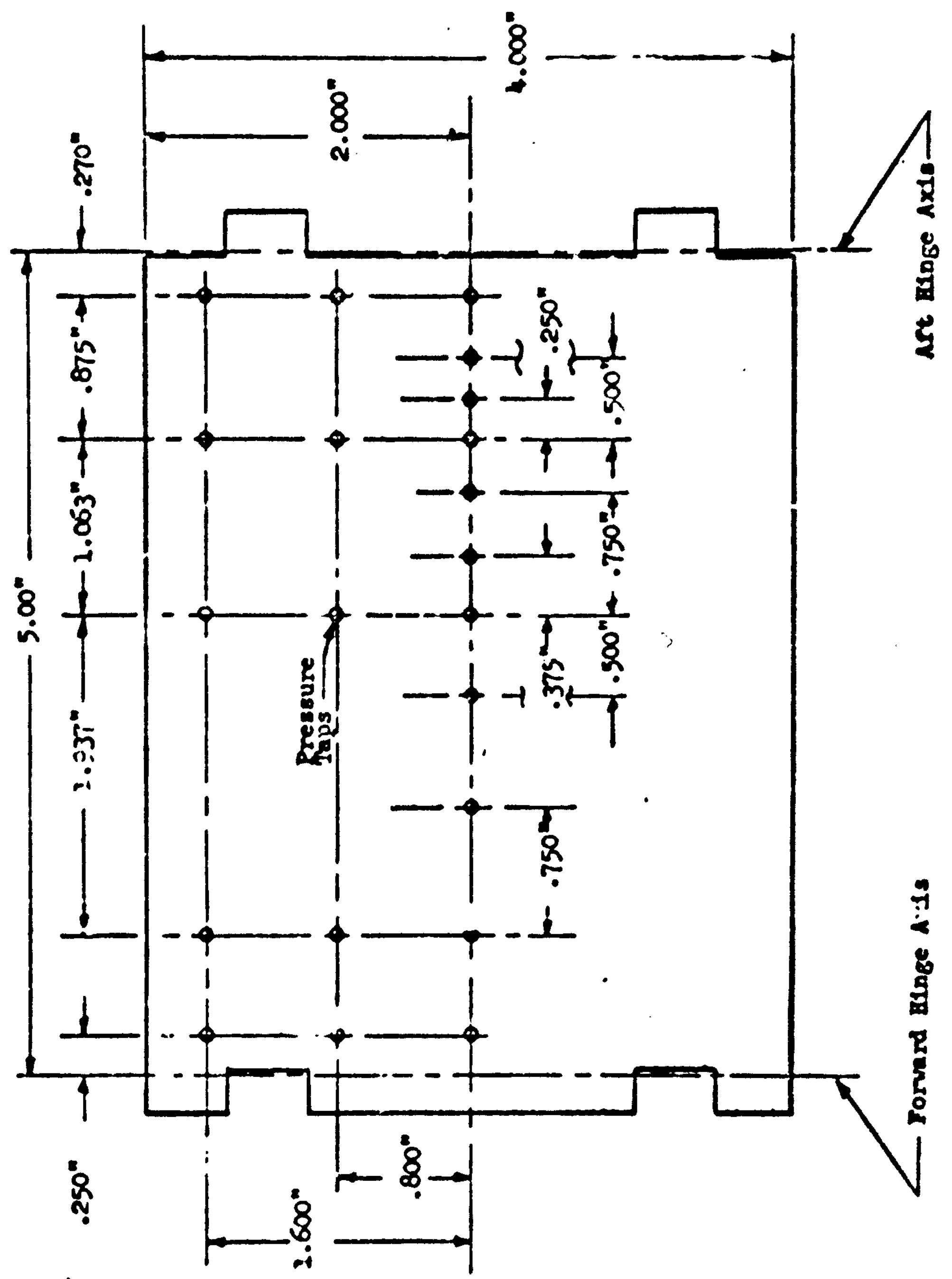
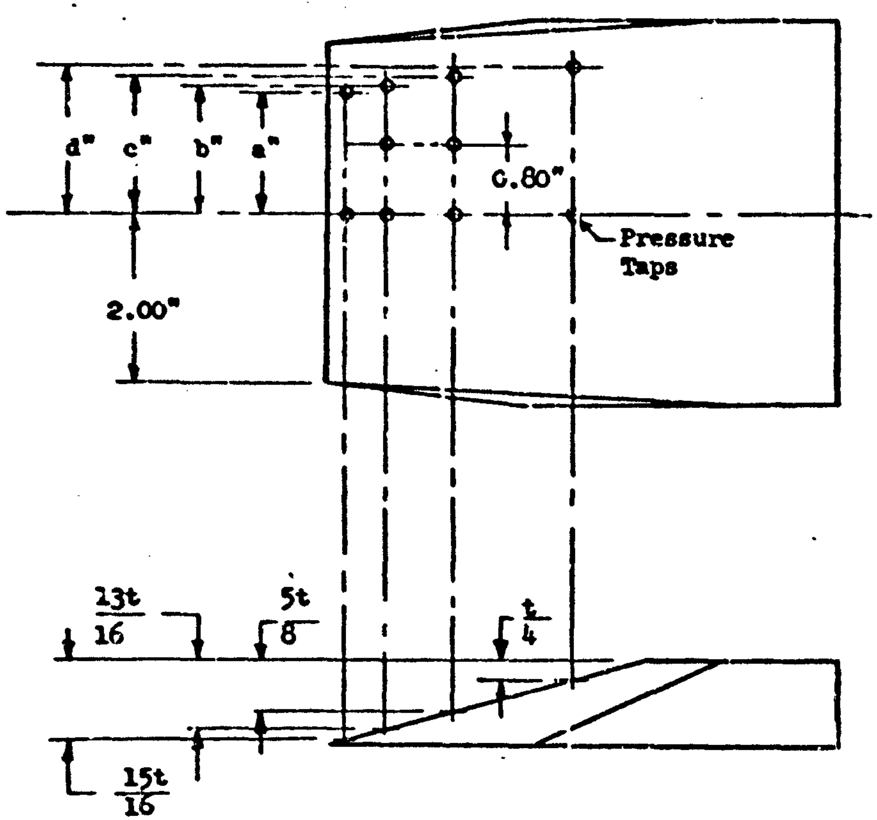
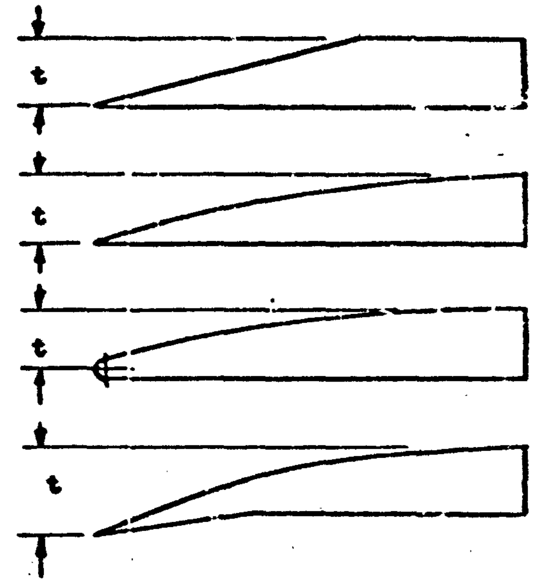


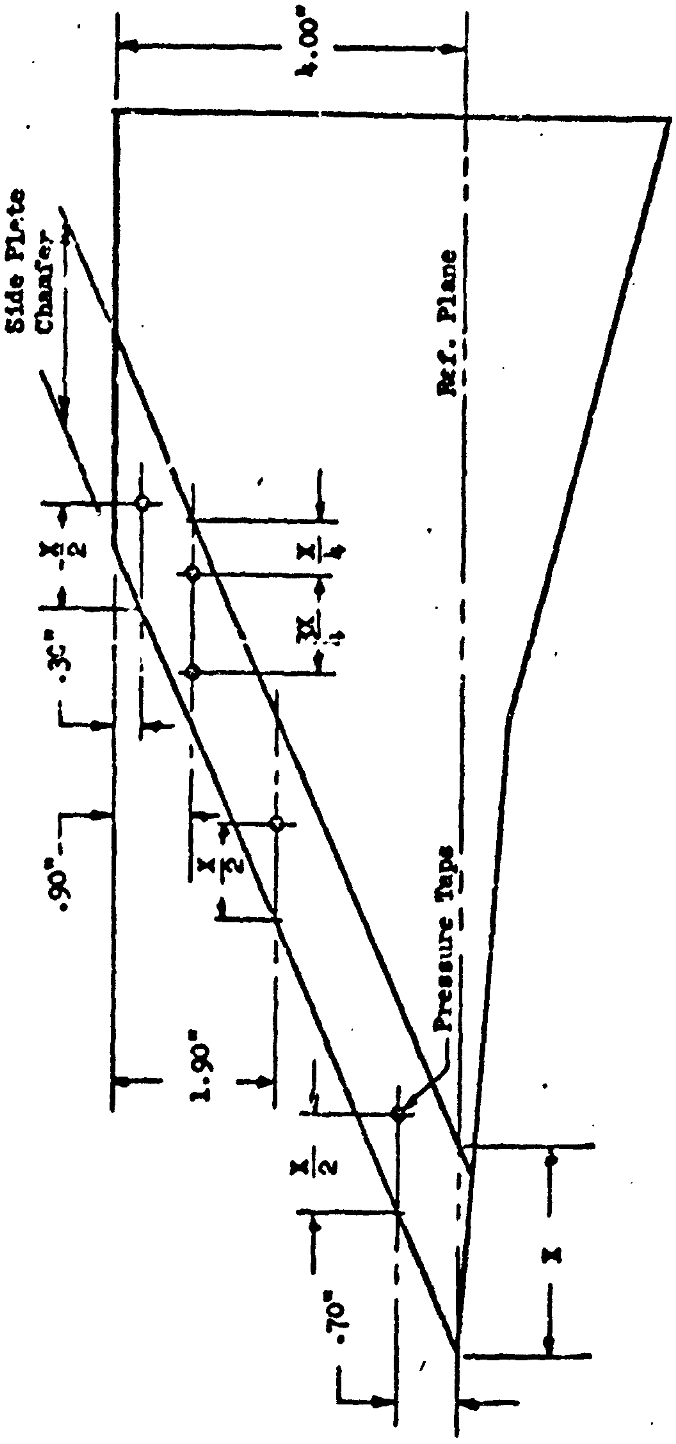
Figure 22 External Moveable Ramp Pressures





Cowl	a	b	c	d
C1	1.61	1.62	1.64	1.70
C2	1.61	1.64	1.68	1.73
C3	1.61	1.62	1.64	1.68
C4	1.61	1.61	1.63	1.66
C5	1.60	1.62	1.63	1.67
C6	1.61	1.62	1.65	1.73
C7	1.60	1.62	1.64	1.69
C8	1.60	1.61	1.62	1.67
C9	1.60	1.60	1.60	1.60
C10	1.60	1.60	1.60	1.60

Figure 23. Cowl Pressures



Note: Only SP1 and SP4 Instrumented

Figure 24. Side Plate Pressures

APPENDIX II

THEORETICAL ADDITIVE DRAG COMPUTATION

1. General. Contract AF 33(615)-2496 required that, prior to testing, mathematical models of theoretical additive drag be hypothesized and that those drags be computed for the contractually required test configurations. A Fortran IV machine program was written for this purpose. This appendix documents the mathematical models and the machine program. In the following pages, the mathematical spillage models are discussed first, followed by the program documentation.

2. Mathematical Model - Subsonic. A free body diagram of the subsonic additive drag situation is given in figure 25. Assuming all flow to enter the inlet in the α direction, the theoretical additive drag is

$$(D_{ADD})_{THEORY} = A_{LIP}\cos\alpha \left[\gamma M_{LIP}^2 P_{LIP} + (P_{LIP} - P_o)\right] + D_R - \gamma A_o M_o^2 P_o$$

Eq. (27)

Then, to determine the theoretical additive drag the following assumptions are made:

Assumption 1) Subsonic flow behaves one-dimensionally (including the assumption that all of the flow entering the inlet is in the α direction);
Assumption 2) Perfect gas ($\gamma = 1.4$);

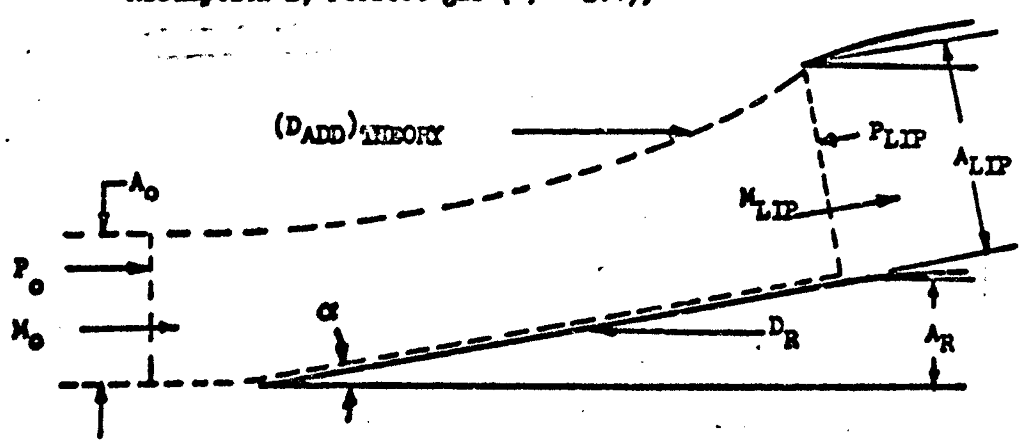


Figure 25. Subsonic Theoretical Additive Drag Momentum Balance

Assumption 3) No subsonic spillage occurs over the side plates;
Assumption 4) All flow processes are isentropic (except thru shock waves);
Assumption 5) $P_R = (P_o + P_{LIP})/2$

The first four assumptions are general and apply to all mathematical models. The fifth assumption applies only to the subsonic case. Assumption 5) enables the calculation of ramp drag,

$$D_R = A_R(P_R - P_o)$$

3. Mathematical Model - Transonic (Detached Initial Shock). The transonic mathematical model of theoretical additive drag is substantially the same as the subsonic model. Assumptions 1) thru 4) apply. Assumption 5) does not. Instead, the average ramp pressure is defined by:

Assumption 6) $P_R = (P_{NS} + P_{LIP})/2$

The average ramp pressure is the arithmetic average of pressure behind a detached normal shock (P_{NS}) and pressure at the lip (P_{LIP}). Again, $(D_{ADD})_{THEORY}$ can be found from equation (15).

4. Mathematical Model - Supersonic (Attached Initial Shock). The supersonic mathematical model and the computer program handle a one external shock wave (one ramp) case only. Model and program can be extended to multiple ramp situations, but contractual computations for which the program was specifically designed were restricted to one ramp cases.

A prime requirement of the models was a simplicity which allows reasonably rapid hand computations of theoretical additive drag. Yet, the mathematical model should produce drag curve shapes similar to measured values if K_{ADD} is to have physical significance. Though this was felt difficult to achieve for the supersonic case, it was successful as is illustrated by figures 45 thru 50.

In the supersonic model, three spillages were considered: supersonic spillage over the cowl, subsonic spillage over the cowl, and supersonic spillage around the inlet side plates. All three spillages are defined below.

On an actual inlet, the terminal shock wave travels fore and aft as a function of subcritical spillage. However, for the mathematical model, Assumption 7) fixes the terminal shock position as illustrated in figure 26.

Assumption 7) The terminal shock wave is defined as a normal shock which has a fixed location an infinitesimal distance forward of the cowl.

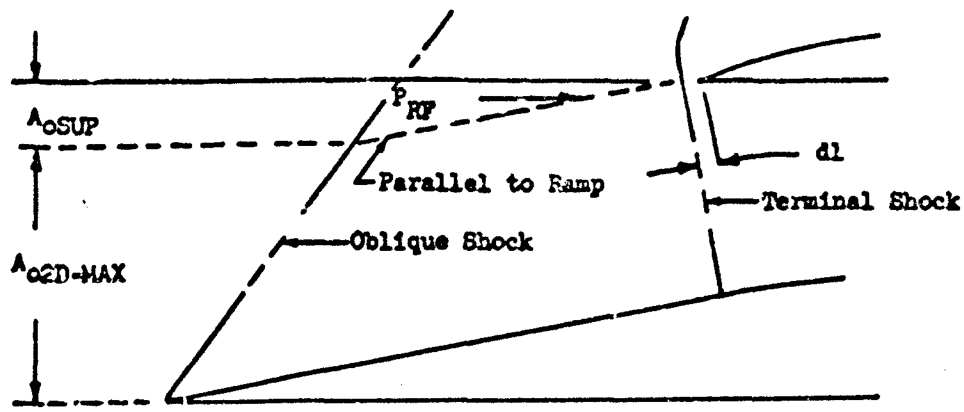


Figure 26. Supersonic Spillage

This assumption leads directly to Assumptions 8) and 9):

Assumption 8) The drag of the air spilled supersonically over the cowl is a fixed value at all mass flow ratios

$$D_{ADD-SUP} = A_{oSUP}(P_{RF} - P_o)$$

where P_{RF} is the pressure behind a two-dimensional oblique shock wave.

Assumption 9) All air spilled subsonically is spilled over the cowl in distance dl. Thus, if side plates are such that side spillage occurs, all side spillage must take place in the supersonic flow region forward of the terminal shock wave.

The mathematical model considers side spillage around inlets that do not have extended side plates. Figure 27 illustrates the area through which side spillage was considered to occur for the mathematical model of an inlet

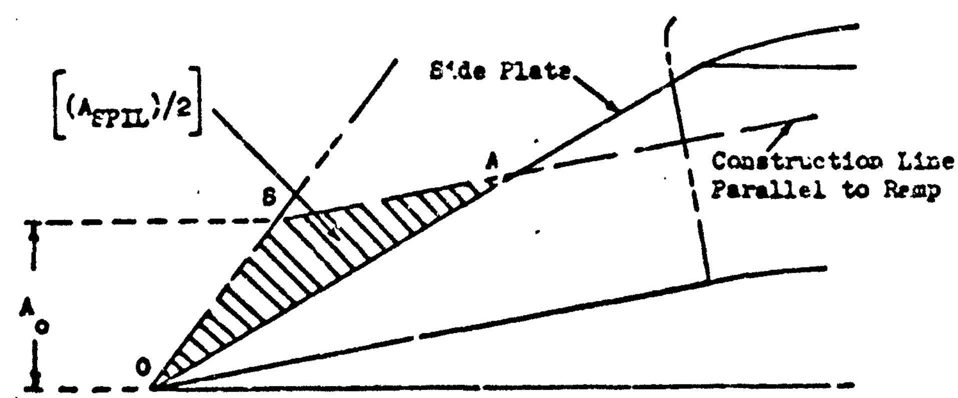


Figure 27. Side Spillage Area

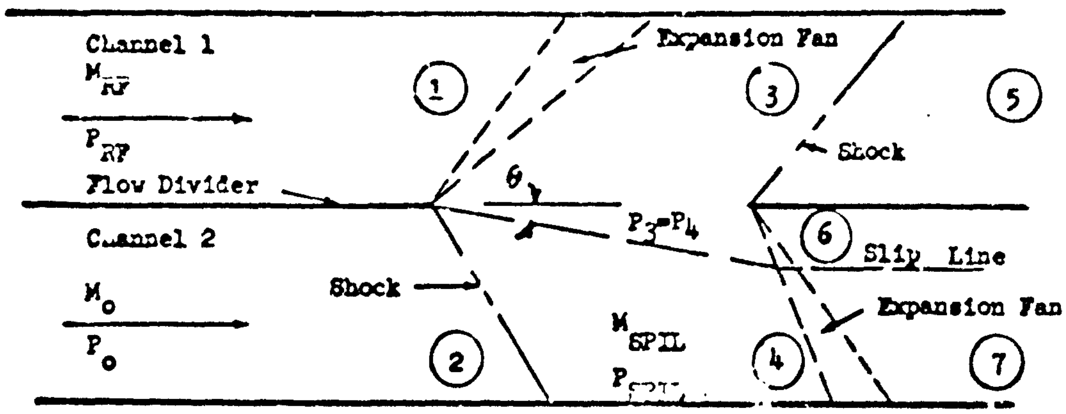


Figure 28. Side Spillage Conditions

having triangular side plates. The inlet shown has freestream tube area A_o entering at the lip. The area 2 OSA = A_{SPIL} is taken as the total side spillage area for the two sides. To determine the drag of side spillage, the spillage pressure P_{SPIL} must be determined.

Figure 28 illustrates a flow situation similar to side spillage. Two channels of flow are shown. Initially they are divided. Downstream the divider is eliminated for a short distance. Channel #1 conditions are initially similar to conditions on the first ramp of an inlet, P_{FR}, M_{FR}. On an inlet they are obtained by ramp turning from the freestream. Channel #2 represents freestream conditions. As the flow passes the opening in the divider, Channel #1 flow expands into Channel #2. This expansion forms an aerodynamic wedge which creates an oblique shock wave in Channel #2, raising its pressure. The slip line angle is such that pressures in regions 3 and 4 are equal. For the small wedge turning angles, α, of conventional inlets, θ is very closely given by

$$\theta \approx \alpha/2$$

Thus,

Assumption 10) M_{SPIL} and P_{SPIL} are obtained by calculating them to be the conditions after turning thru the wedge half angle from the freestream.

The side spill flow is found from the continuity equation to be

$$A_{oSPIL} = A_{SPIL} \frac{P_{SPIL}}{P_o} \frac{M_{SPIL}}{M_o} \sin\left(\frac{\alpha}{2}\right) \left[\frac{1 + \frac{\gamma - 1}{2} M_{SPIL}^2}{1 + \frac{\gamma - 1}{2} M_o^2}\right]^{1/2}$$

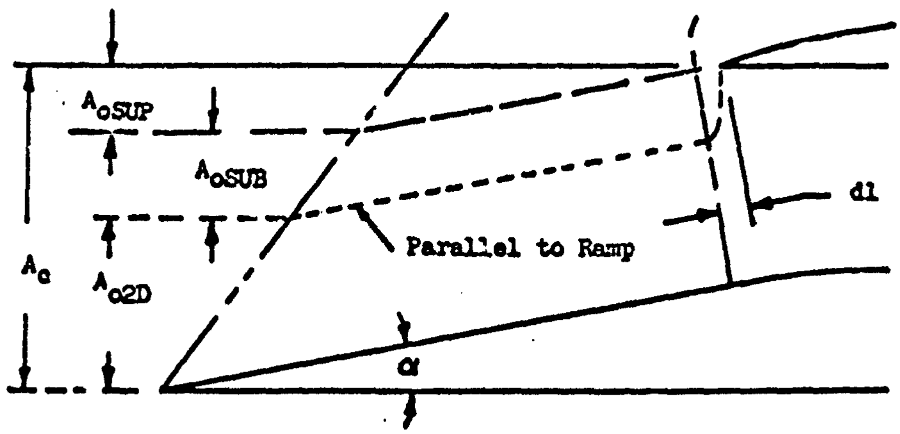


Figure 29. Flow Field Forward of Terminal Shock
(No Side Spillage)

and the side spillage drag is

$$D_{ADD-SPIL} = A_{oSPIL}(P_{SPIL} - P_o)$$

In addition to supersonic spillage over the cowl and around the side plates, the mathematical model considers subsonic spillage over the cowl from behind the terminal shock. For the case of an inlet having extended side plates such that no side spillage can occur, figure 29 illustrates the mathematical model flow conditions in the supersonic region forward of the terminal shock wave. Here, flow A_o enters the inlet. Flow A_{cSUP} is spilled supersonically over the cowl, and flow A_{oSUB} is spilled subsonically over the cowl in distance dl. Figure 30 is a blow-up of the cowl lip region illustrating

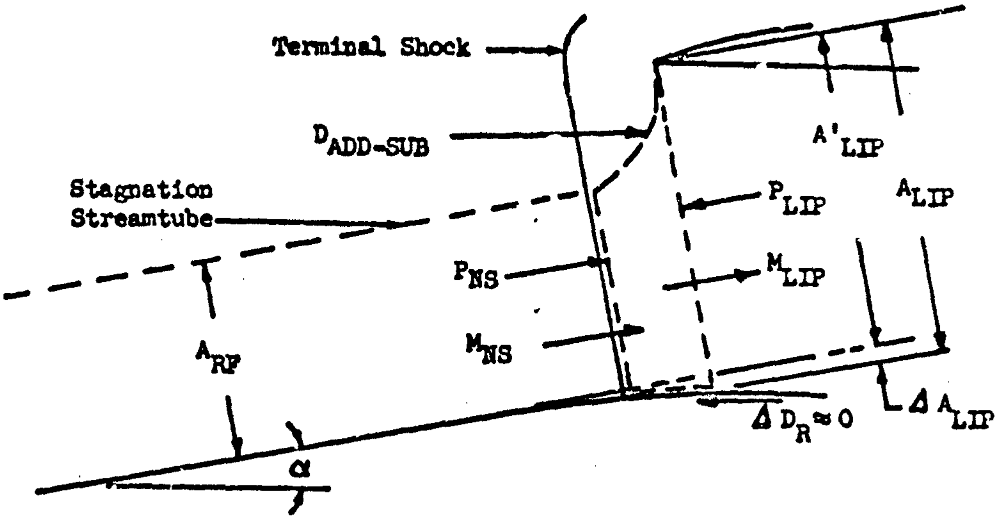


Figure 30. Subsonic Spillage

subsonic spillage behind the terminal shock. The free body force-momentum diagram for obtaining subsonic spillage drag, $D_{ADD-SUB}$, is also shown.

For a few inlet configurations the ramp may "break away" significantly from a straight line ahead of the cowl lip plane, thus producing an expansion of the ramp flow by ΔA_{LIP} (see figure 30). On the wind tunnel model the "break away" was minor. It has been neglected in the mathematical model for simplicity of hand computations.

Assumption 11) The external ramp is defined as a flat surface at angle α up to the cowl lip plane.

Assumptions 10) and 11), respectively, imply and define the supersonic flow conditions on the ramp as being fixed. Assumption 10) implies that P_{RF} and M_{RF} do not change with side spillage, and Assumption 11) eliminates effects of minor ramp curvatures. Assumption 12), below, clearly states this invariance between oblique shock wave and terminal shock wave.

Assumption 12) For inlets with side spillage or minor ramp curvatures, the Mach number and the pressure along the ramp are assumed to be constant and equal to the conditions behind the oblique ramp shock wave.

The subsonic spillage drag by a force-momentum balance is

$$D_{ADD-SUB} = \gamma \cos\alpha \left(P_{LIP} A'_{LIP} M^2_{LIP} - P_{NS} A_{NS} M^2_{NS}\right)$$

$$+ \cos\alpha \left[A'_{LIP} \left(P_{LIP} - P_o\right) - A_{NS}\left(P_{NS} - P_o\right)\right]$$

Figure 31 shows the complete flow field with supersonic spillage, subsonic spillage and side spillage. As the flow travels up the ramp behind the oblique shock some of the air is spilled over the sides, and the stagnation streamtube expands to A_{RF}, although Assumption 12) neglects the effect of this expansion on P_{RF} and M_{RF}. Thus, the mathematical model ramp flow conditions are those of a two-dimensional inlet (no side spillage) with a freestream tube area equal to A_{oEFF} where

$$A_{oEFF} = A_o + A_{oSPIL}$$

and

$$A_{RF} = A_{oEFF} \left(A_{RF}/A^*\right) / \left(H_{RF}/H_o\right) \left(A_o/A^*\right)$$

The total theoretical additive drag for the supersonic case is, then, the sum of the three spillage drags

$$\left(D_{ADD}\right)_{THEORY} = D_{ADD-SUP} + D_{ADD-SUB} + D_{ADD-SPIL}$$

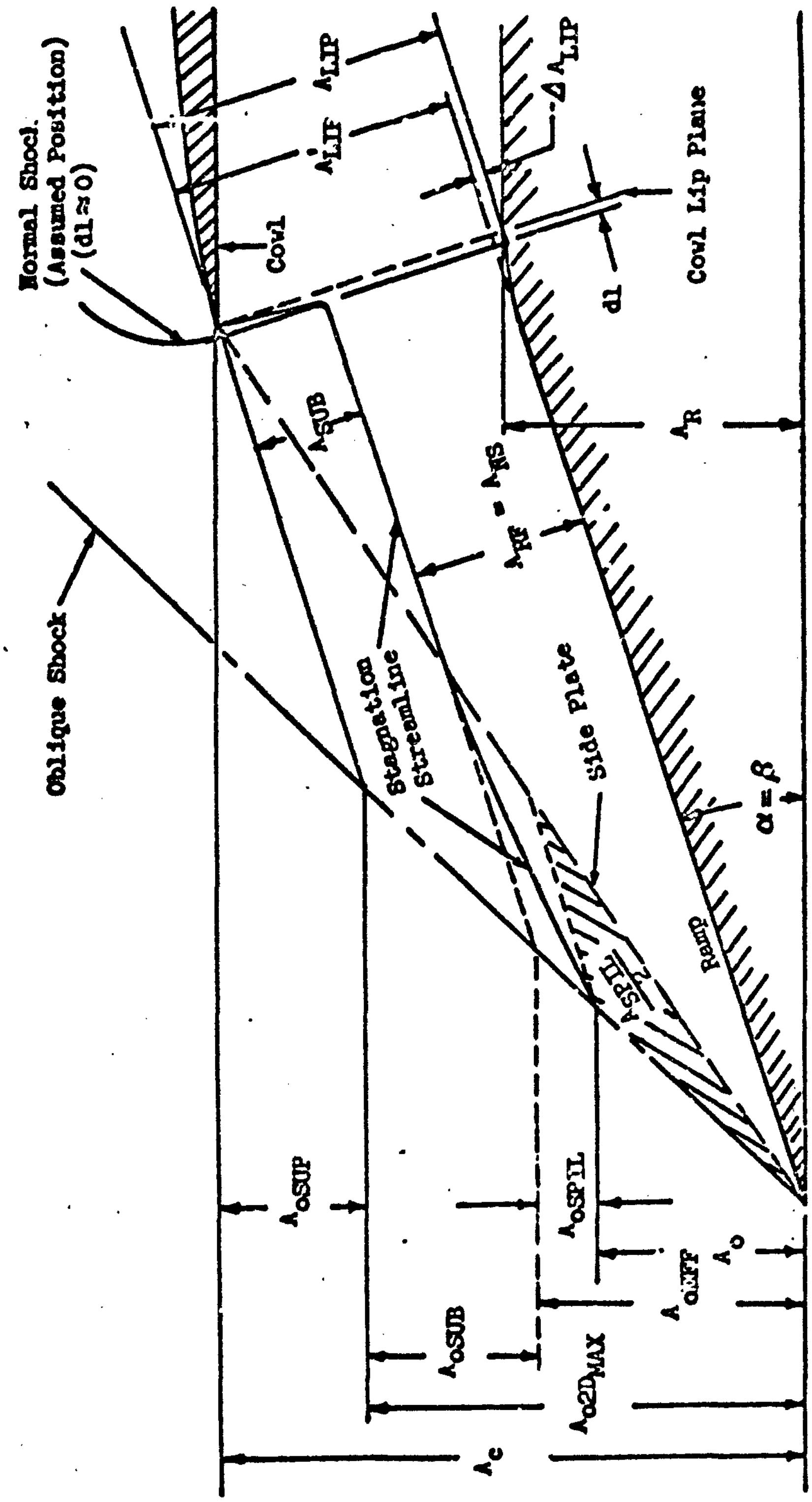


Figure 31. Inlet Supersonic Flow Field and Nomenclature

where, in summary,

$$D_{ADD-SUP} = A_{oSUP}(P_{RP} - P_o)$$

$$D_{ADD-SUB} = \gamma \cos\alpha \left(P_{LIP} A'_{LIP} M_{LIP}^2 - P_{ES} A_{ES} M_{ES}^2\right) + \cos\alpha \left[A'_{LIP}(P_{LIP} - P_o) - A_{ES}(P_{ES} - P_o)\right]$$

$$D_{ADD-SPIL} = A_{oSPIL}(P_{SPIL} - P_o)$$

5. Machine Program. The main program of the rectangular inlet additive drag program solves the $(D_{ADD})_{THEORY}$ equations just described. Table I is a listing of program subroutines. A complete set of flow diagrams and a program listing are included in figures 32 and 33. The supersonic branch includes an iteration process that calculates the maximum mass flow ratio which the inlet can ingest, assuming no internal choking. This routine is entered if the sum of the input mass flow and the side spillage is greater than $A_{o2D-MAX}$. A sample of the output for this case and other output cases are included in figures 34 thru 38. Figure 39 shows the print out key, and table II is a listing of print out definitions.

Two major subroutines included in the program are discussed below. Flow diagrams and program listings for these are included in figures 40, 41, 42, and 43.

The Ideal Deflection (IDEF) subroutine calculates the flow conditions behind attached oblique shock waves using equations from reference 14. If an oblique shock solution is not possible, the main program calculates flow conditions behind a normal shock using equations from the same reference.

The Side Spillage (SPIL) subroutine calculates the freestream tube area of the air that spills supersonically around inlet side plates. It is limited to inlets having only one oblique shock, as is the main program, and to the side plate shapes used in this test. The side spillage area is found by the use of congruent triangles and the known inlet geometry as shown in figure 44. Use is made of the plane geometry theorem:

> For two congruent triangles, the ratio of their areas is equal to the square of the ratio of a representative dimension.

Now A_o is a representative dimension of the triangle OSA, and $A_{o2D-MAX}$ is the corresponding dimension of OEC. Similarly, $(A_{o2D-MAX} - A_o)$ is a representative dimension of ACB, and $A_{o2D-MAX}$ is the corresponding representative dimension of OCE.

$$OSA = A_{MAX-ST} \left(A_o / A_{o2D-MAX}\right)^2$$

$$ABC = A_{DM}\left[(A_{o2D-MAX} - A_o)/A_{o2D-MAX}\right]^2$$

$$A_{SPIL} = 2\left[A_{MAX-ST}\,(A_o/A_{o2D-MAX})^2 + A_{CUT} - A_{DM}\,(1 - A_o/A_{o2D-MAX})^2\right]$$

The continuity equation can now be used to convert the stream area of the spilled air to a freestream tube area.

$$A_{oSPIL} = A_{SPIL}(P_{SPIL}/P_o)\,(M_{SPIL}/M_o)\sin(\alpha/2)\left[\frac{1+\frac{\gamma-1}{2}M_{SPIL}^2}{1+\frac{\gamma-1}{2}M_o^2}\right]^{1/2}$$

Although any amount of "cut back" area can be used, A_{oSPIL} should not be calculated for mass flows less than A_{oMIN} (see figure 44). To use the program for extended or "two-dimensional" side plates, a large negative number must be put in for A_{CUT}/A_c and zero for A_{DM}/A_c.

Table I

Machine Program Subroutines

Subroutine	Description
GTIS (Main)	Control Program. Also does the majority of the calculations of Additive Drag.
SPIL	Calculates freestream tube area that is spilled supersonically around the side plates.
IDEF	Calculates the conditions behind a two dimensional attached oblique shock.
DECR	Reads in data. If more than one case is being run it is only necessary to have input cards on the inputs that are different than the preceding case. If no new value is given for a particular input it will use the same value that was used in the preceding case
CLEA	Sets the data storage region to zero.
ARCCOS	Calculates the arccosine.
ARCSIN	Calculates the arcsine.
ARCTAN	Calculates the arctangent.
COSSIN	Calculates sine and cosine.
CUBI	Solves basic cubic equation.
CURTOO	Calculates cube root.
SQRT	Calculates square root.

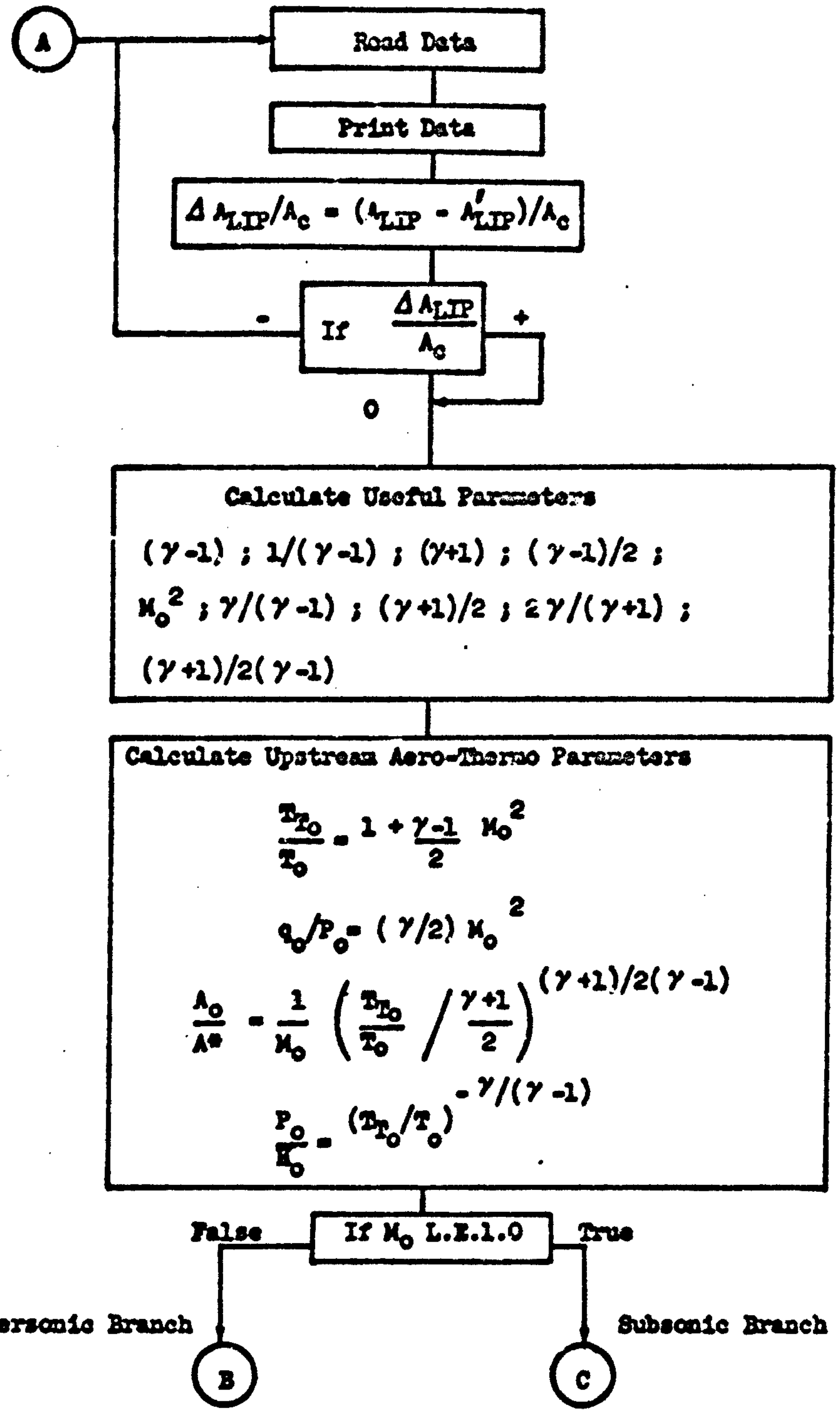


Figure 32. Main Program

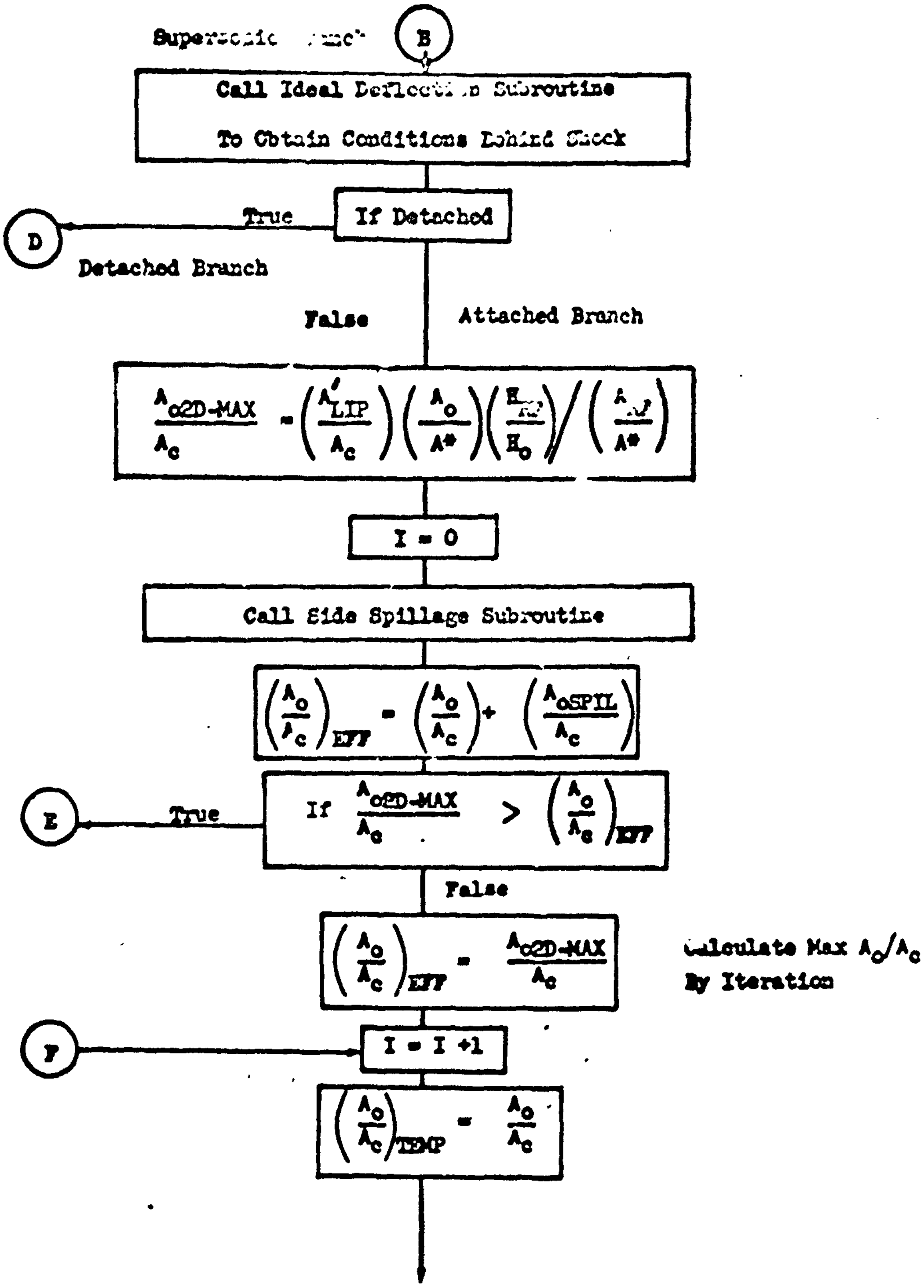


Figure 32. Continued

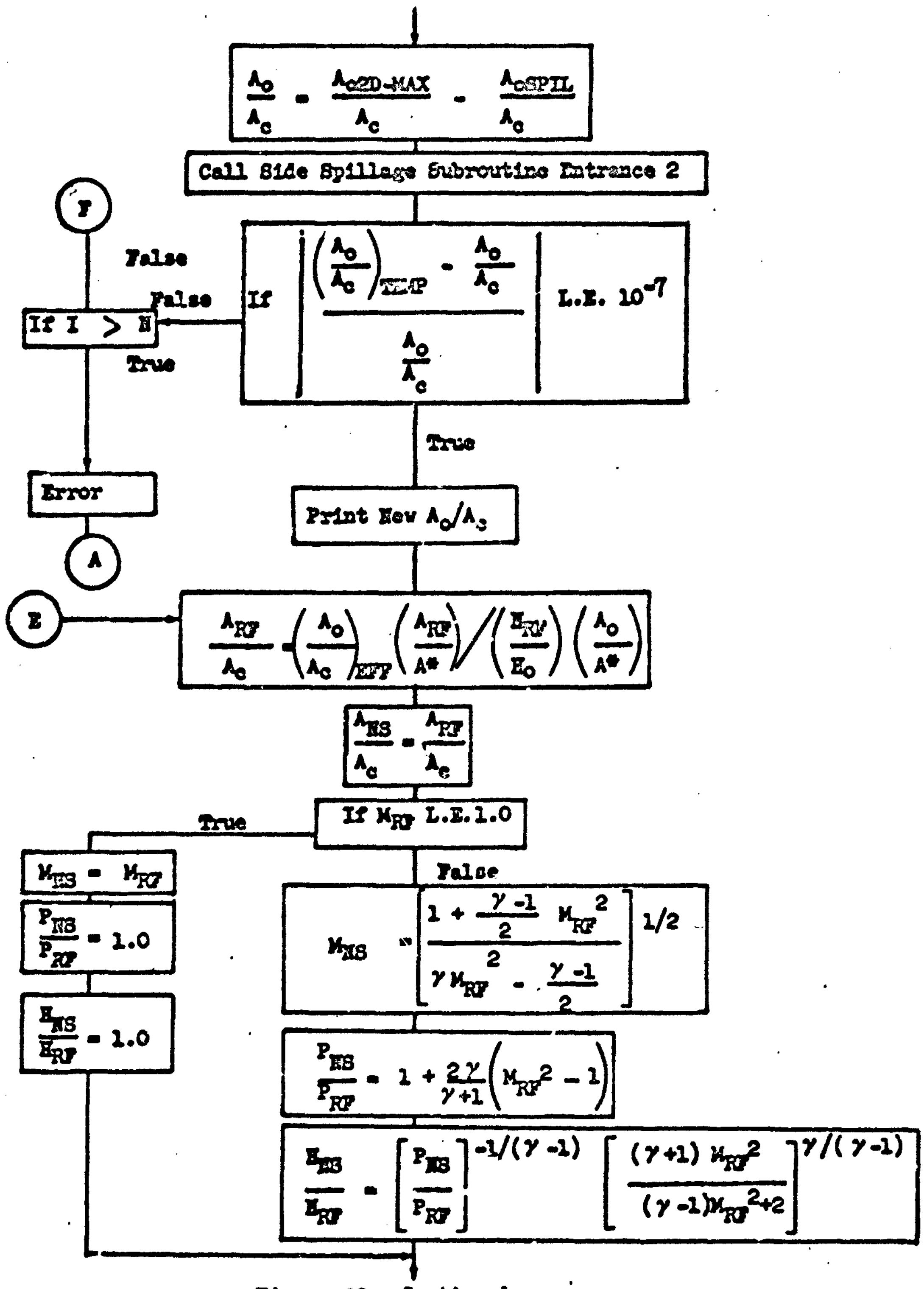


Figure 32. Continued

$$\frac{P_{NS}}{P_o} = \left(\frac{P_{NS}}{P_{RF}}\right)\left(\frac{P_{RF}}{P_o}\right)$$

$$\frac{A_{NS}}{A^*} = \frac{1}{M_{NS}}\left[\frac{2 + (\gamma - 1) M_{NS}^2}{(\gamma + 1)}\right]^{(\gamma+1)/2(\gamma-1)}$$

$$\frac{A_{LIP}}{A^*} = \left(\frac{A'_{LIP}}{A_c}\right)\left(\frac{A_{NS}}{A^*}\right)\Big/\left(\frac{A_{NS}}{A_c}\right)$$

Calculate M_{LIP} Using the Newton Method of Iteration on the Expression:

$$\frac{A_{LIP}}{A^*} = \frac{1}{M_{LIP}}\left[\frac{2 + (\gamma - 1) M_{LIP}^2}{(\gamma + 1)}\right]^{(\gamma+1)/2(\gamma-1)}$$

Use Initial Value of M_{LIP} Near Inflection

First Try $(M_{LIP}) = 0.3$

If Does Not Converge

A

$$\left(\frac{P_{LIP}}{H_{LIP}}\right) = \left[1 + \frac{\gamma - 1}{2} M_{LIP}^2\right]^{-\gamma/(\gamma-1)}$$

$$\frac{P_{LIP}}{P_o} = \left(\frac{P_{LIP}}{H_{LIP}}\right)\left(\frac{H_{NS}}{H_{RF}}\right)\left(\frac{H_{RF}}{H_o}\right)\Big/\left(\frac{P_o}{H_o}\right)$$

$$C_{C_{ADD-SUB}} = \frac{2}{\gamma M_o^2}\left[\left(\frac{P_{LIP}}{P_o}\frac{A'_{LIP}}{A_c} M_{LIP}^2 - \frac{P_{NS}}{P_o}\frac{A_{NS}}{A_c} M_{NS}^2\right)\gamma\cos\alpha - \frac{A_{RF}}{A_c}\left(\frac{P_{NS}}{P_o} - 1\right)\cos\alpha + \frac{A'_{LIP}}{A_c}\left(\frac{P_{LIP}}{P_o} - 1\right)\cos\alpha\right]$$

Figure 32. Continued

$$\frac{A_{oSUP}}{A_c} = 1.0 - \frac{A_{o2D-MAX}}{A_c}$$

$$\frac{A_{oSUB}}{A_c} = \frac{A_{o2D-MAX}}{A_c} - \left(\frac{A_o}{A_c}\right)_{EFF}$$

$$C_{C_{ADD-SUP}} = \frac{A_{oSUP}}{A_c}\left(\frac{P_{RF}}{P_o} - 1\right)\frac{2}{\gamma M_o^2}$$

$$C_{C_{ADD-SPIL}} = \frac{A_{oSPIL}}{A_c}\left(\frac{P_{SPIL}}{P_o} - 1\right)\frac{2}{\gamma M_o^2}$$

$$C_{C_{ADD-q}} = C_{C_{ADD-SUB}} + C_{C_{ADD-SUP}} + C_{C_{ADD-SPIL}}$$

$$C_{C_{ADD-P}} = \left(C_{C_{ADD-q}}\right) q_o/P_o$$

Print Output

A

Figure 32. Continued

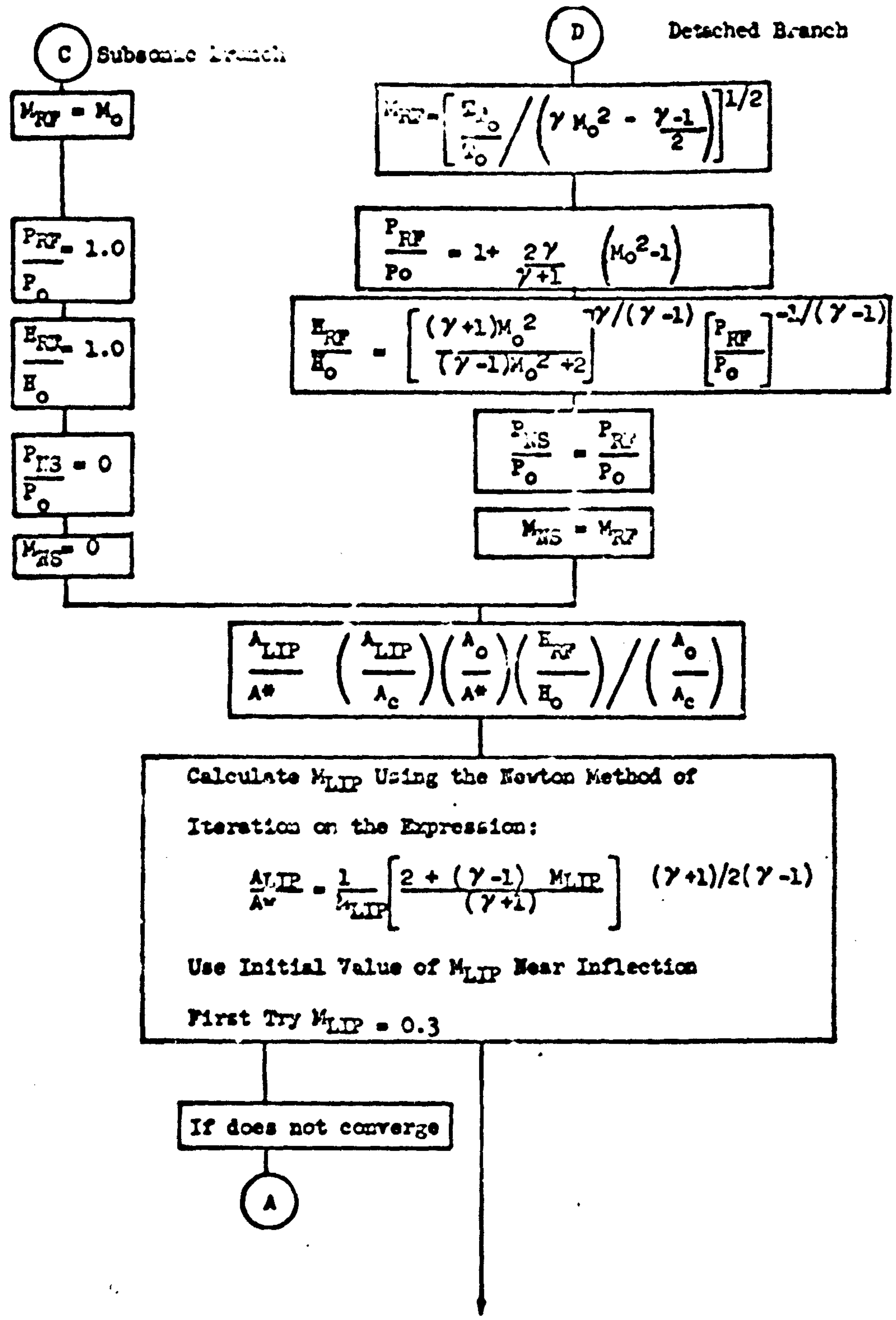


Figure 32. Continued

$$\left(\frac{P_{LIP}}{H_{LIP}}\right) = \left[1 + \frac{\gamma - 1}{2} M_{LIP}^2\right]^{-\gamma/(\gamma-1)}$$

$$\frac{P_{LIP}}{P_o} = \left(\frac{P_{LIP}}{H_{LIP}}\right)\left(\frac{H_{RF}}{H_o}\right)\Big/\left(\frac{P_o}{H_o}\right)$$

$$\frac{P_R}{P_o} = \frac{1}{2}\left(\frac{P_{RF}}{P_o} + \frac{P_{LIP}}{P_o}\right)$$

$$C_{C_{ADD-P}} = \frac{A_{LIP}}{A_c} \cos\alpha \left[\gamma M_{LIP}^2 \left(\frac{P_{LIP}}{P_o}\right) + \left(\frac{P_{LIP}}{P_o} - 1\right)\right] + \left(\frac{A_R}{A_c}\right)\left(\frac{P_R}{P_o} - 1\right) - \gamma M_o^2 \left(\frac{A_o}{A_c}\right)$$

$$C_{C_{ADD-q}} = \left(C_{C_{ADD-P}}\right) P_o/q_o$$

$$C_{C_{ADD-SPIL}} = 0 \; ; \quad C_{C_{ADD-SUP}} = 0$$

$$C_{C_{ADD-SUB}} = C_{C_{ADD-q}} \; ; \quad \frac{A_{oSPIL}}{A_c} = 0$$

$$\frac{A_{oSUB}}{A_c} = 1 - \frac{A_o}{A_c} \; ; \quad \frac{A_{oSUP}}{A_c} = 0$$

Print Output

A

Figure 32. Concluded

```
                                                                        09/18736
        GTIS      -  EFN   SOURCE STATEMENT  -  IFN(S)  -

          DIMENSION CR(15)                                              GTIS0040
          COMMON CR                                                     GTIS0050
          REAL MO,MOSQ,MNSSQ,MRFSQ,MRF,MNS,ML,MLSQ,MFPM                 GTIS0080
C     1 GAM    RATIO SPECIFIC HEATS, ISENTROPIC EXPONENT                GTIS0110
C     2 W      RAMP WIDTH (SIDE-PLATE SPREAD                        IN. GTIS0120
C     3 ALFD   RAMP (FLOW DEFLECTION) ANGLE                        DEG GTIS0130
C     4 ALAC   AREA RATIO (LIP TO CAPTURE)                              GTIS0140
C     5 APLAC  AREA RATIO (PROJECTED-RAMP LIP TO CAPTURE)               GTIS0150
C     6 ACUT   TRIANGULAR SIDE PLATE AREA MINUS SIDE PLATE AREA (RATIO) GTIS0160
C     7 AIM    IMAGINARY SIDE PLATE AREA USED IN CONGRUENT TRIANGLE RATIO GTIS0170
C     8 X      HORIZONTAL DISTANCE FROM LE TO COWL LIP              IN. GTIS0180
C     9 Y      VERTICAL DISTANCE FROM LE TO COWL LIP                IN. GTIS0190
C    10 ARAC   RAMP FRONTAL AREA TO INLET LIP STATION                   GTIS0195
C    11 AOAC   UPSTREAM FLOW AREA RATIO                                 GTIS0210
C    12 MO     UPSTREAM MACH NO.                                        GTIS0220
C       ALF    RAMP ANGLE                                           RAD GTIS0310
C       AOHAC  SUPERSONIC (HIGH) AREA RATIO (UPSTREAM TO CAPTURE)       GTIS0320
C       AOLAC  SUBSONIC (LOW) AREA RATIO                                GTIS0325
C       CDADH  SUPERSONIC (HIGH) COEF OF ADDITIVE DRAG                  GTIS0330
C       CDADL  SUBSONIC (LOW) COEF OF ADDITIVE DRAG                     GTIS0340
C       CDADP  COEF OF ADDITIVE DRAG BASED ON P(O)                      GTIS0350
C       CDADQ  COEF OF ADDITIVE DRAG BASED ON Q(O)                      GTIS0360
C       CDADSP SPILL COEF OF ADDITIV DRAG                               GTIS0370
C       DALAC  LIP AREA RATIO INCREMENT                                 GTIS0380
C       DM     ITERATION INCREMENT OF LIP MACH NO.                      GTIS0390
C       ER     ERROR INDICATOR                                          GTIS0400
C       FGAM   2*GAMMA/(GAMMA+1)                                        GTIS0410
C       FM     ITERATION FUNCTION                                       GTIS0415
C       F1     T(LIP)/T(*)                                              GTIS0420
C       GPO2GM (GAMMA+1)/2/(GAMMA-1), AREA FUNCTION EXPONENT            GTIS0440
C       MFPM   -DERIVATIVE OF ITERATION FUNCTION                        GTIS0443
C       PLOPO  LIP TO UPSTREAM PRESSURE RATIO                           GTIS0445
C       POHL   LIP INVERSE RAM PRESSURE RATIO                           GTIS0450
C       POHO   UPSTREAM INVERSE RAM PRESSURE RATIO                      GTIS0460
C       QUPO   UPSTREAM DYNAMIC PRESSURE RATIO                          GTIS0470
C       SNBTSQ SINE(DEFLECTED FLOW SHOCK ANGLE)**2                      GTIS0480
```

Figure 33. Main Program Listing

```
                                                                  09/18/36
         GTIS       - EFN   SOURCE STATEMENT  -  IFN(S)  -
C      TTOTO  RAM TEMPERATURE RATIO                                GTIS0490
       EQUIVALENCE (GAM,CR(1)),(W,CR(2)),(ALFD,CR(3)),(ALAC,CR(4)),(APLACGTIS0510
      1,CR(5)),(ACUT,CR(6)), (AIM,CR(7)),(X,CR(8)),(Y,CR(9)),(ADAC,CR(11)GTIS0511
      2),(MO,CR(12)),(ARAC,CR(10)),(EN,CR(13))                     GTIS0512
CLEAR COMMON REGION                                                GTIS0520
       CALL CLEAR (CR,15)                                          GTIS0530
C READ DATA INTO COMMON REGION                                      GTIS0580    2
   10 CALL DECRD (CR)                                              GTIS0590
C PRINT INPUT DATA                                                 GTIS0600    4
       WRITE(6,30)(CR(I),I=1,13)                                   GTIS0610    5
   30 FORMAT(1H11P5E19.7/(1HC5E19.7))                              GTIS0620
CALC LIP AREA INCREMENT                                            GTIS0630
       DALAC=ALAC-APLAC                                            GTIS0640
CHECK, NEXT CASE IF -                                              GTIS0650
       IF(DALAC)10,40,40                                           GTIS0660
CALC PRIMARY USEFUL PARAMETERS                                     GTIS0670
   40 ER=.0                                                        GTIS0680
       N=EN                                                        GTIS0685
       GM1=GAM-1.                                                  GTIS0690
       RGM1=1./GM1                                                 GTIS0695
       GP1=GAM+1.                                                  GTIS0700
       GM102=.5*GM1                                                GTIS0710
       MOSQ=MO**2                                                  GTIS0720
       ALF=ALFD/57.2957795                                         GTIS0725
       GOGM1=GAM/GM1                                               GTIS0730
       GP102=.5*GP1                                                GTIS0740
       FGAM=GAM/GP102                                              GTIS0745
       GP02GM=GP102/GM1                                            GTIS0750
CALC UPSTREAM AERO-THERMO PARAMETERS                               GTIS0760
       TTOTO=1.+GM102*MOSQ                                         GTIS0765
       QOPO=.5*GAM*MOSQ                                            GTIS0767
       AOAS=(TTOTO/GP102)**GP02GM/MC                               GTIS0770   15
       POHO=TTOTO**(-GOGM1)                                        GTIS0790   16
       IF(MO.LE.1.)GOTO80                                          GTIS0795
C 'IDDEF' S/R FOR DEFLECTION FLOW PARAMETERS                        GTIS0800
       CALL IDDEF (MOSQ,GAM,ALF,SNBTSQ,HRFHC,MRFSQ,MRF,PRFPO,ARFAS,ER)  GTIS0810
C IF DETACHED                                                      GTIS0820   20
```

Figure 33. Continued

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                                                                  09/18/36
        GTIS        -  EFN   SOURCE STATEMENT  -  IFN(S)  -
      IF(ER)50,50,90                                             GT IS0830
   50 AO2DAC=APLAC*AOAS/ARFAS*MRFHC                              GT IS0840
      I=0                                                        GT IS0841
      CALL SPILL (AOAC,MO,MOSQ,AO2DAC,X,Y,SNBTSQ,ACUT,AIM,GAM,TTOTO,AOACGT IS0850
     1SP,ALF,W,PSPPO)                                            GT IS0851   25
      IF(ER.GT.O.)GOTO90                                         GT IS0855
   55 AOACEF=AOAC+AOACSP                                         GT IS0860
      IF(AO2DAC.GT.AOACEF)GOTO 57                                GT IS0861
      AOACEF=AO2DAC                                              GT IS0862
   51 I=I+1                                                      GT IS0863
      ATEMP=AOAC                                                 GT IS0864
      AOAC=AO2DAC - AOACSP                                       GT IS0865
      CALL SPILL2(AOAC,MO,MOSQ,AO2DAC,X,Y,SNBTSQ,ACUT,AIM,GAM,TTOTO,AOACGT IS0866
     1SP,ALF,W,PSPPO)                                            GT IS0867   36
      IF(ER.GT.O.)GOTO90                                         GT IS0868
      DELT=ATEMP-AOAC                                            GT IS0869
      IF(ABS(DELT/AOAC).LE.1.E-7)GOTO54                          GT IS0870
      IF(I.GT.N)GOTO52                                           GT IS0871
      GOTO51                                                     GT IS0872
   52 WRITE(6,53)                                                GT IS0873   42
   53 FORMAT(1HO 4X, 20HDIVERGING AT MAX MFR)                    GT IS0874
      GOTO10                                                     GT IS0875
   54 WRITE(6,56) AOAC                                           GT IS0876   50
   56 FORMAT(1HO 4X, 26HMFR TOO LARGE SO USED MFR=, 1E14.7)      GT IS0877
   57 ARFAC=AOACEF/MRFHO*ARFAS/ACAS                              GT IS0878
      AMSAC=ARFAC                                                GT IS0880
      IF(MRF.LE.1.) GO TO 58                                     GT IS0885
      MNSSQ=(1.+GM1D2*MRFSQ)/(GAM*MRFSQ-GM1D2)                   GT IS0890
      MNS=SQRT(MNSSQ)                                            GT IS0900   55
      PNSPRF=1.+FGAM*(MRFSQ-1.)                                  GT IS0920
      MNSHRF=(GP1/(GM1+2./MRFSQ))**GOGM1/PNSPRF**RGM1            GT IS0930   56   57
      GO TO 59                                                   GT IS0931
   58 MNS=MRF                                                    GT IS0932
      PNSPRF=1.                                                  GT IS0933
      MNSHRF=1.                                                  GT IS0934
      MNSSQ=MNS**2                                               GT IS0935
   59 PNSPO=PNSPRF*PRFPO                                         GT IS0940
```

Figure 33. Continued

```
      GTIS     - EFN   SOURCE STATEMENT  -  IFN(S)  -              09/20/36
      ANSAS=((2.+GM1*MNSSQ)/GP1)**GPO2GM/MNS                        GTIS0950    61
      ALAS=APLAC*ANSAS/ANSAC                                        GT9S0960
CALC M(LIP) BY ITERATION. START WITH AN M(LIP) NEAR INFLECTION TO INSUREGTIS0964
CONVERGENCE. NEWTON METHOD  DELTA M(LIP)=-F(M(LIP))/F(PRIME)(M(LIP))  GTIS0965
      ML=.3                                                         GTIS0970
      I=0                                                           GTIS0975
   60 MLSQ=ML**2                                                    GTIS0980
      F1=(2.+GM1*MLSQ)/GP1                                          GTIS0990
      F2=F1**GPO2GM                                                 GTIS1000    63
      I=I+1                                                         GTIS1005
      FM=ALAS-F2/ML                                                 GTIS1010
      MFPM=F2*(1./F1-1./MLSQ)                                       GTIS1020
      DM=FM/MFPM                                                    GTIS1030
      ML=ML+DM                                                      GTIS1040
      IF(ABS(DM/ML).LE.1.E-7)GOTO66                                 GTIS1050
      IF(I.LT.N)GOTO60                                              GTIS1055
      GOTO10                                                        GTIS1056
   66 MLSQ=ML**2                                                    GTIS1060
CALC DRAG COEFFICIENTS                                              GTIS1065
      POHL=(1.+GM1O2*MLSQ)**(-GOGM1)                                GTIS1070    73
      PLOPO=POHL*HNSHRF/POHO*HRFHO                                  GTIS1080
      CDADL=COS(ALF)*((PLOPO*APLAC*MLSQ-PNSPO*ANSAC*MNSSQ)*GAM-ARFAC*(PNGTIS1090
     1SPO-1.)+APLAC*(PLOPO-1.))/QOPO                                GTIS1100    74
      AOHAC=1.-AO2DAC                                               GTIS1110
      AOLAC=AO2DAC-AOACEF                                           GTIS1115
      CDADH=AOHAC*(PRFPO-1.)/QOPO                                   GTIS1120
      CDADSP=AOACSP*(PSPPO-1.)/QOPO                                 GTIS1130
      CDADO=CDADL+CDADH+CDADSP                                      GTIS1140
      CDADP=CDADO*QOPO                                              GTIS1150
C PRINT REQUIRED OUTPUT                                             GTIS1155
   67 WRITE(6,70)CDADP,CDADO,CDADL,CDADH,CDADSP,PLOPO,AOACSP,AOLAC ,AOHAGTIS1160
     1C,MRF,PRFPO,HRFHO,MNS,PNSPO,ML                                GTIS1170    75
   70 FORMAT(1H0 1P5E20.7)                                          GTIS1180
C BACK FOR NEXT CASE. WILL EXIT IF FINISHED                         GTIS1185
      GOTO10                                                        GTIS1190
C SUBSONIC BRANCH                                                   GTIS1195
   80 MRF=MO                                                        GTIS1200
```

Figure 33. Continued

```
                                                                      09/18/36
          GTIS        -  EFN   SOURCE STATEMENT  -  IFN(S)  -
             PRFPO=1.                                                 GT IS1210
             MRFMO=1.                                                 GT IS1220
             PNSPO=0.                                                 GT IS1221
             MNS=0.                                                   GT IS1222
             GOTO100                                                  GT IS1230
      C DETACHED INITIAL SHOCK BRANCH                                 GT IS1235
          90 MRFSQ=TTOTO/(GAM*MOSQ-GM1O2)                             GT IS1240
             MRF=SQRT(MRFSQ)                                          GT IS1250   80
             PRFPO=1.+FGAM*(MOSQ-1.)                                  GT IS1260
             MRFMO=(GP1/(GM1+2./MOSQ))**GOGM1/PRFPO**RGM)             GT IS1270   81     82
             PNSPO=PRFPO                                              GT IS1271
             MNS=MRF                                                  GT IS1272
         100 ALAS=ALAC*AOAS/AOAC*MRFMO                                GT IS1280
             ML=.3                                                    GT IS1290
             I=0                                                      GT IS1295
         110 MLSQ=ML**2                                               GT IS1300
             F1=(2.+GM1*MLSQ)/GP1                                     GT IS1310
             F2=F1**GPO2GM                                            GT IS1320   85
             I=I+1                                                    GT IS1325
             FM=ALAS-F2/ML                                            GT IS1330
             MFPM=F2*(1./F1-1./MLSQ)                                  GT IS1340
             DM=FM/MFPM                                               GT IS1350
             ML=ML+DM                                                 GT IS1360
             IF(ABS(DM/ML).LE.1.E-7)GOTO120                           GT IS1370
             IF(I.LT.N)GOTO110                                        GT IS1375
             GOTO10                                                   GT IS1376
         120 MLSQ=ML**2                                               GT IS1380
             POML=(1.+GM1O2*MLSQ)**(-GOGM1)                           GT IS1390   95
             PLOPO=POML*MRFMO/POMO                                    GT IS1400
             PROPO=.5*(PRFPC+PLOPO)                                   GT IS1410
             CDADP= COS(ALF)*ALAC*(GAM*PLOPO*MLSC+PLOPO-1.)+ARAC*(PROPO-1.)-GAMGT IS1420
            1*AOAC*MOSQ                                               GT IS1430   96
             CDADQ=CDADP/QOPO                                         GT IS1440
             CDADSP=0.                                                GT IS1441
             CDADM=0.                                                 GT IS1442
             CDADL=CDADQ                                              GT IS1443
             AOACSP=0.                                                GT IS1444
```

Figure 33 Continued

```
      GTIS         - EFN   SOURCE STATEMENT  -  IFN(S)  -                09/18/36

     AOLAC=1.-ACAC                                                       GTIS1445
     AOHAC=0.                                                            GTIS1446
     GOTO67                                                              GTIS1450
     END                                                                 GTIS1460
```

Figure 33. Concluded

1.4000000E 00	4.0000000E 00	5.0000000E 00	7.9625000E-01	7.9425000E-01
0.0000000E-39	0.0000000E-39	9.3600000E 00	4.0000000E 00	2.0680000E-01
8.5000000E-01	6.9200000E-01	2.5000000E 01		
-1.1255243E-02	-3.3577232E-02	-3.3577232E-02	0.0000000E-39	0.0000000E-39
8.8622914E-01	0.0000000E-39	1.5000000E-01	0.0000000E-39	6.9200000E-01
1.0000000E 00	1.0000000E 00	0.0000000E-39	0.0000000E-39	8.1928713E-01

Figure 34. Standard Print Out Format

1.4000000E 00	4.0000000E 00	5.0000000E 00	7.9625000E-01	7.9425000E-01
0.0000000E-39	0.0000000E-39	9.3600000E 00	4.0000000E 00	2.0680000E-01
9.0000000E-01	6.9200000E-01	2.5000000E 01		

NOTE: Input mass flow ratio too large, choking at cowl lip plane

Figure 35. Subsonic Case

1.4000000E 00	4.0000000E 00	5.0000000E 00	7.9625000E-01	7.9425000E-01
0.0000000E-39	0.0000000E-39	9.3600000E 00	4.0000000E 00	2.0680000E-01
8.0000000E-01	1.0930000E 00	2.5000000E 01		

DETACHED

3.5035804E-02	4.1896113E-02	4.1896113E-02	0.0000000E-39	0.0000000E-39
1.1682613E 00	0.0000000E-39	2.0000000E-01	0.0000000E-39	9.1726417E-01
1.2270905E 00	9.5912674E-01	9.1726417E-01	1.2270905E 00	9.6122157E-01

Figure 36. Transonic (Detached Shock) Case

1.4000000E 00	4.0000000E 00	5.0000000E 00	7.9625000E-01	7.9425000E-01
0.0000000E-39	0.0000000E-39	9.3600000E 00	4.0000000E 00	2.0680000E-01
9.0000000E-01	1.0930000E 00	2.5000000E 01		

DETACHED

NOTE: Input mass flow ratio too large, choking at cowl lip plane

Figure 37. Transonic (Detached Shock) Case

```
1.4000000E 00     4.0000000E 00     5.0000000E 00     7.9625000E-01     7.9425000E-01
9.0000000E-39     0.0000000E-39     9.3600000E 00     4.0000000E 00     2.0680000E-01
8.0000000E-01     1.2930000E 00     2.5000000E 01
MFR TOO LARGE SO USED MFR= 0.7803931E 00
  5.8808803E-02     5.0251294E-02     8.5619566E-08     4.3465917E-02     6.7852926E-03
  1.5697074E 00     5.8154777E-02     0.0000000E-39     1.6145214E-01     1.0798022E 00
  1.3150650E 00     9.9790943E-01     9.2787485E-01     1.5697076E 00     9.2787499E-01
```

NOTE: Input mass flow ratio too large, program computes data using maximum possible mass flow ratio.

Figure 38. Supersonic Case

γ	θ	α	A_{LIP}/A_c	A'_{LIP}/A_c
A_{CUT}/A_c	A_{BL}/A_c	X	Y	A_B/A_c
A_o/A_c	Re			

$C_{C_{ADD-P}}$	$C_{C_{ADD-q}}$	$C_{C_{ADD\ SUB}}$	$C_{C_{ADD\ SUP}}$	$C_{D_{ADD\ SPILL}}$
P_{LIP}/P_o	A_o^{SPILL}/A_c	A_o^{SUB}/A_c	A_o^{SUP}/A_c	M_{SP}
P_{BF}/P_o	M_{BF}/M_o	M_{NS}	P_{NS}/P_o	M_{LIP}

Figure 39. Print Out Key

Table II

Print Out Definitions

Symbol	Definitions
A_{CUT}/A_c	Side plate are ratio minus triangular side plate area ratio.
A_{D4}/A_c	An imaginary area used in side spillage calculation as the known part of a congruent triangle area ratio.
A_{LIP}/A_c	Inlet lip station area ratio measured from cowl leading edge to ramp surface measured perpendicular to the flat part of the second ramp.
A_{LIP}/A_c	Inlet lip station area ratio measured from cowl leading edge to a straight line extension of the forward part of the second ramp measured perpendicular to the forward part of the second ramp.
A_R/A_c	Ramp frontal area ratio measured from first ramp leading edge to inlet lip station defined in A_{LIP}/A_c $(1 - A_{LIP} \cos\beta / A_c)$
A_{oSPIL}/A_c	Mass flow ratio spilled supersonicly around the side.
A_{oSUB}/A_c	Mass flow ratio spilled subsonically over the cowl.
A_{oSUP}/A_c	Mass flow ratio spilled supersonicly over the cowl.
A_o/A_c	Mass flow ratio entering the inlet.
$C_{C_{ADD-P}}$	Additive drag coefficient, (D/P_oA_c).
$C_{C_{ADD-q}}$	Additive drag coefficient, (D/q_oA_c).
$C_{C_{ADD-SPIL}}$	Portion of additive drag due to supersonic spillage of the air around the sides, (D/q_oA_c).
$C_{C_{ADD-SUB}}$	Portion of additive drag due to subsonic spillage of the air over the cowl, (D/q_oA_c).
$C_{C_{ADD-SUP}}$	Portion of additive drag due to supersonic spillage of the air over the cowl, (D/q_oA_c).
H_{RP}/H_o	Total pressure ratio on the ramp.

Table II Continued

Symbol	Definitions
M_{LIP}	Mach number at the inlet lip station.
M_{NS}	Mach number behind the normal shock.
M_{RF}	Initial Mach number on the ramp, (for supersonic M_{RF} is assumed constant over the total ramp).
M_o	Freestream Mach number.
P_{LIP}/P_o	Static pressure ratio at lip station.
P_{NS}/P_o	Static pressure ratio behind the normal shock.
P_{RF}/P_o	Initial static pressure ratio on the ramp.
W	Inlet width
X	Horizontal distance from the first ramp leading edge to the cowl leading edge (in inches).
Y	Vertical distance from the first ramp leading edge to the cowl leading edge (in inches).
α	First ramp angle - from freestream.
γ	Specific heat ratio.

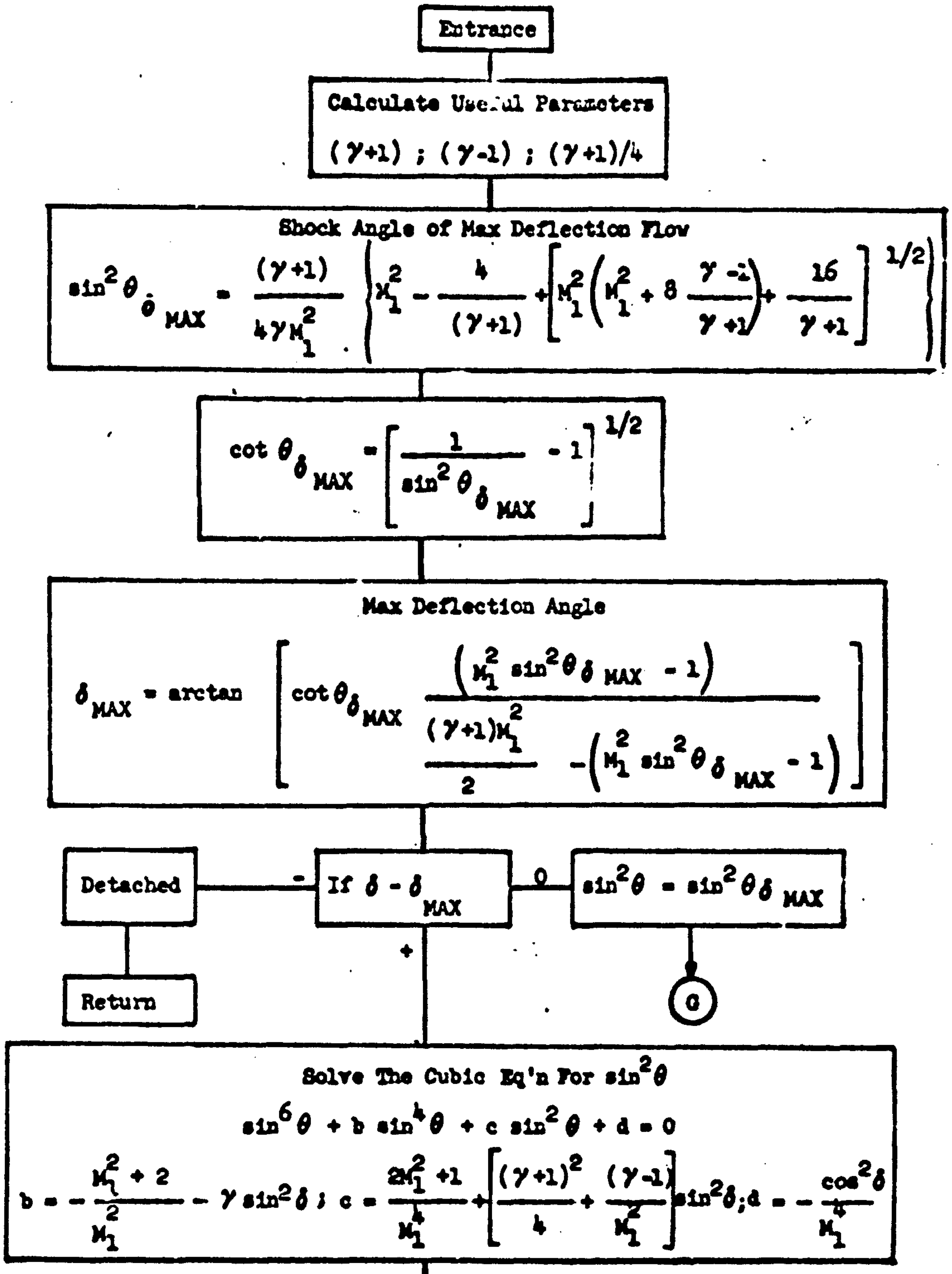


Figure 40 Ideal Deflection Subroutine

$$M_N^2 = M_1^2 \sin^2\theta$$

G

$$\frac{P_2}{P_1} = \frac{2\gamma M_1^2 \sin^2\theta - (\gamma - 1)}{(\gamma + 1)}$$

$$\frac{H_2}{H_1} = \frac{\left[\dfrac{(\gamma+1) M_1^2 \sin^2\theta}{(\gamma-1) M_1^2 \sin^2\theta + 2}\right]^{\gamma/(\gamma-1)}}{\left(\dfrac{P_2}{P_1}\right)^{1/(\gamma-1)}}$$

$$M_2^2 = \frac{(\gamma+1)^2 M_1^4 \sin^2\theta - 4\,(M_1^2 \sin^2\theta - 1)\,(\gamma M_1^2 \sin^2\theta + 1)}{\left[2\gamma M_1^2 \sin^2\theta - (\gamma-1)\right]\left[(\gamma-1) M_1^2 \sin^2\theta + 2\right]}$$

$$M_2 = \sqrt{M_2^2}$$

$$\frac{A_2}{A^*} = \frac{1}{M_2}\left[\frac{2 + (\gamma-1) M_2^2}{(\gamma+1)}\right]^{(\gamma+1)/2(\gamma-1)}$$

Return

Figure 40. Concluded

```
                                                                        09/18/36
          IDEF        - EFN   SOURCE STATEMENT  -  IFN(S)  -

      SUBROUTINE IDDEF (M1SQ,GAM,DEL,SNTHSC,H2OH1,M2SQ,M2,P2OP1,A2OAS,ERIDEF0030
     1)                                                                  IDEF0031
C REFERENCE.. NACA REPORT NO. 1135 OF 1953                               IDEF0035
C     A2OAS  DOWNSTREAM AREA RATIO                                      IDEF0038
C     B,C,D  COEF'S OF X**3+B*X**2+C*X+D=C (X=SNTHSQ)   EQ.(150)        IDEF0040
C     CTTDM  COTANGENT(SHOCK ANGLE OF MAXIMUM DEFLECTION FLOW)          IDEF0050
C     DEL    FLOW DEFLECTION ANGLE                                   RAD IDEF0060
C     DELM   MAXIMUM ATTACHED-SHOCK FLOW-DEFLECTION ANGLE            RAD IDEF0070
C     ER     INDICATOR (DETACHED SHOCK IF OVER 0)                       IDEF0080
C     GAM    RATIO OF SPECIFIC HEATS                                    IDEF0090
C     H2OH1  RATIO OF STAGNATION PRESSURES ACROSS SHOCK                 IDEF0100
C     MNSQ   (NORMAL COMPONENT OF MACH NO.)**2 AND AN INTERMEDIATE FUNC.IDEF0110
C     M1SQ   (UPSTREAM MACH NO.)**2                                     IDEF0120
C     M2     DOWNSTREAM MACH NO.                                        IDEF0125
C     M2SQ   (DOWNSTREAM MACH NO.)**2                                   IDEF0130
C     M14TH  (UPSTREAM MACH NO.)**4                                     IDEF0140
C     NR     NO. ROOTS OF CUBIC EQUATION                                IDEF0143
C     P2OP1  RATIO PRESSURES ACROSS SHOCK                               IDEF0145
C     R1,R2,R3 ROOTS OF CUBIC EQUATION                                  IDEF0146
C     SNTDMS SINE(SHOCK ANGLE OF MAXIMUM DEFLECTION FLOW)**2            IDEF0150
C     SNTHSQ SINE(SHOCK ANGLE)**2                                       IDEF0160
      REAL M1SQ,M2SQ,M14TH,MNSQ,M2                                      IDEF0170
CALC FUNCTIONS TO BE USED                                               IDEF0180
      GP1=GAM+1.                                                        IDEF0190
      GM1=GAM-1.                                                        IDEF0200
      GP1O4=.25*GP1                                                     IDEF0210
CALC MAXIMUM FLOW DEFLECTION ANGLE                                      IDEF0220
      SNTDMS=GP1O4/GAM*(M1SQ-4./GP1+SQRT(M1SQ*(M1SQ+2.*GM1/GP1O4)+4./GP1IDEF0230
     1O4))/M1SQ                                                          IDEF0240     2
      CTTDM=SQRT(1./SNTDMS-1.)                                          IDEF0250     3
      MNSQ=M1SQ*SNTDMS-1.                                               IDEF0260
      DELM=ARCTAN(CTTDM*MNSQ/(.5*GP1*M1SQ-MNSQ))                        IDEF0270
CHECK DEFLECTION VS MAXIMUM ALLOWABLE                                   IDEF0300     4
      IF(DEL-DELM)50,40,20                                              IDEF0310
C PRINT 'DETACHED' SET INDICATOR AND RETURN                             IDEF0320
   20 WRITE(6,30)                                                       IDEF0330     6
```

Figure 41. Ideal Deflection Subroutine Listing

```
          IDEF        - EFN   SOURCE STATEMENT  -  IFN(S)  -                 09/18/36
      30 FORMAT(9HODETACHED)
         ER=1.                                                               IDEF0340
         GOTO150                                                             IDEF0350
 C JUST ATTACHED, SET SHOCK ANGLE = ANGLE OF MAXIMUM DEFLECTION              IDEF0360
      40 SNTHSQ=SNTCMS                                                       IDEF0370
         GOTO140                                                             IDEF0380
 C ATTACHED, CALC SHOCK ANGLE                                                IDEF0390
      50 SNDSQ=SIN(DEL)**2                                                   IDEF0400
         M14TH=M1SQ**2                                                       IDEF0410    11
 COEFFICIENTS OF CUBIC IN SINE(THETA)**2, EQ.(150)                           IDEF0420
         B=-(1.+2./M1SQ+GAM*SNDSQ)                                           IDEF0430
         C=(2.*M1SQ+1.)/M14TH+(.25*GP1**2+GM1/M1SQ)*SNDSQ                    IDEF0440
         D=(SNDSQ-1.)/M14TH                                                  IDEF0450
 CUBIC S/R GIVES ROOTS                                                       IDEF0460
         CALL CUBIC (B,C,D,R1,R2,R3,NR)                                      IDEF0480
         EN=NR                                                               IDEF0490    12
 CHECK NO. ROOTS, 1=DETACHED, 2=JUST ATTACHED, 3= NORMAL ATTACHMENT          IDEF0500
         IF(NR-2)20,40,60                                                    IDEF0520
 CORRECT ROOT IS MIDDLE ROOT                                                 IDEF0530
      60 IF(R2-R3)100,40,70                                                  IDEF0540
      70 IF(R2-R1)130,40,80                                                  IDEF0550
      80 IF(R1-R3)110,40,90                                                  IDEF0560
      90 SNTHSQ=R1                                                           IDEF0570
         GOTO140                                                             IDEF0580
     100 IF(R1-R3)120,40,110                                                 IDEF0590
     110 SNTHSQ=R3                                                           IDEF0600
         GOTO140                                                             IDEF0610
     120 IF(R2-R1)90,40,130                                                  IDEF0620
     130 SNTHSQ=R2                                                           IDEF0630
 CALC NEEDED PARAMETERS                                                      IDEF0640
     140 MNSQ=M1SQ*SNTHSQ                                                    IDEF0650
 C F'S ASSIST SOLUTION                                                       IDEF0660
         F1=GAM*MNSQ                                                         IDEF0670
         F2=2.*F1-GM1                                                        IDEF0680
         F3=F1+MNSQ                                                          IDEF0690
         F4=F1-MNSQ+2.                                                       IDEF0700
         P2OP1=F2/GP1                                                        IDEF0710
                                                                             IDEF0715
```

Figure 41. Continued

```
                                                                  09/18/36
        IDEF      - EFN   SOURCE STATEMENT  - IFN(S) -

      M20H1=(F3/F4)**(GAM/GM1)/P20P1**(1./GM1)                   IDEF0720   31   32
      M2SQ=(GP1*M1SQ*F3-4.*(MNSQ-1.)*(F1+1.))/F2/F4              IDEF0730
      M2=SQRT(M2SQ)                                              IDEF0733   33
      A20AS=((2.+GM1*M2SQ)/GP1)**(.5*GP1/GM1)/M2                 IDEF0736
COMPLETION                                                       IDEF0740   34
  150 RETURN                                                     IDEF0760
      ENC                                                        IDEF0770
```

Figure 41. Concluded

Entrance

$$\frac{A_{MAX-ST}}{A_c} = \frac{1}{2}\left[\frac{A_{c2D-MAX}}{A_c}\right]\frac{1}{W}\left[X - Y\,\frac{\sqrt{1-\sin^2\beta}}{\sin\beta}\right]$$

Call Ideal Deflection Subroutine To Obtain Side Spill Conditions

Entrance #2

$$\frac{A_{SPIL}}{A_c} = 2\left[\frac{A_{MAX-ST}}{A_c}\left(\frac{A_o/A_c}{A_{c2D-MAX}/A_c}\right)^2 + \frac{A_{CUT}}{A_c}\,\frac{A_{IM}}{A_c}\left(1-\frac{A_o/A_c}{A_{c2D-MAX}/A_c}\right)^2\right]$$

If $\frac{A_{SPIL}}{A_c}$: $-$ → $\frac{A_{SPIL}}{A_c} = 0$; 0, $+$ → continue

$$\frac{A_{oSPIL}}{A_c} = \left(\frac{A_{SPIL}}{A_c}\right)\left(\frac{P_{SPIL}}{P_o}\right)\frac{M_{SPIL}}{M_o}\sin\left(\frac{\alpha}{2}\right)\left[\frac{1+\frac{\gamma-1}{2}M_{SPIL}^2}{1+\frac{\gamma-1}{2}M_o^2}\right]^{1/2}$$

Return

Figure 42. Side Spillage Subroutine

```
                                                                09/18/36
      SPIL      - EFN   SOURCE STATEMENT  -  IFN(S)  -

      SUBROUTINE SPILL (AOAC,MC,MOSO,AO2DAC,X,Y,SNBTSO,ACUT,AIM,GAM,TTOTSPIL0030
     1O,AOACSP,ALF,W,PSPPO)                                             SPIL0031
      REAL MO,MOSO,MSP,MSPSO                                            SPIL0040
      ASPACM=.5*AO2DAC/W*(X-Y*SQRT(1./SNBTSO-1.))                       SPIL0200    2
      ALFO2=.5*ALF                                                      SPIL0210
      CALL IODEF (MOSO,GAM,ALFO2,SNBSO2,MSPMO,MSPSO,MSP,PSPPO,ASPAS,ER) SPIL0220
C ER MAY INDICATE TROUBLE IN IODEF S/R, START NEXT CASE                 SPIL0221    3
      IF(ER.GT.0.0) GO TO 20                                            SPIL0222
      GO TO 10                                                          SPIL0223
      ENTRY   SPILL2   (AOAC,MC,MOSO,AO2DAC,X,Y,SNBTSO,ACUT,AIM,GAM,TTOTSPIL0230
     1O,AOACSP,ALF,W,PSPPO)                                             SPIL0231
   10 ASPAC=2.*(ASPACM*(AOAC/AO2DAC)**2+ACLT-AIM*(1.-(AOAC/AO2DAC))**2) SPIL0235
      IF(ASPAC)1,2,2                                                    SPIL0236
    1 ASPAC=.0                                                          SPIL0237
    2 AOACSP=ASPAC*PSPPO/MO*MSP*SIN(ALFO2)*SQRT((1.+.5*(GAM-1.)*MSPSO)/TSPIL0240
     1TOTO)                                                             SPIL0241    14    15
   20 RETURN                                                            SPIL0250
      END                                                               SPIL0260
```

Figure 43.   Side Spillage Subroutine Listing

$A_{SPILL} = 2(OSED)$ $\qquad A_{cut} = OCD$ $\qquad A_{IM} = OCR$ $\qquad A_{MAX-ST} = OBC$

$A_{SPIL} = 2(OSA+OCD-ACB)$

$$A_{SPILL} = 2\left[A_{MAX-ST}\left(\frac{A_o}{A_{o2D-MAX}}\right)^2 + A_{CUT} - A_{IM}\left(1 - \frac{A_o}{A_{o2D-MAX}}\right)^2\right]$$

Assumes $A_o > A_{cMIN}$ (Stagnation Streamline Above Point D)

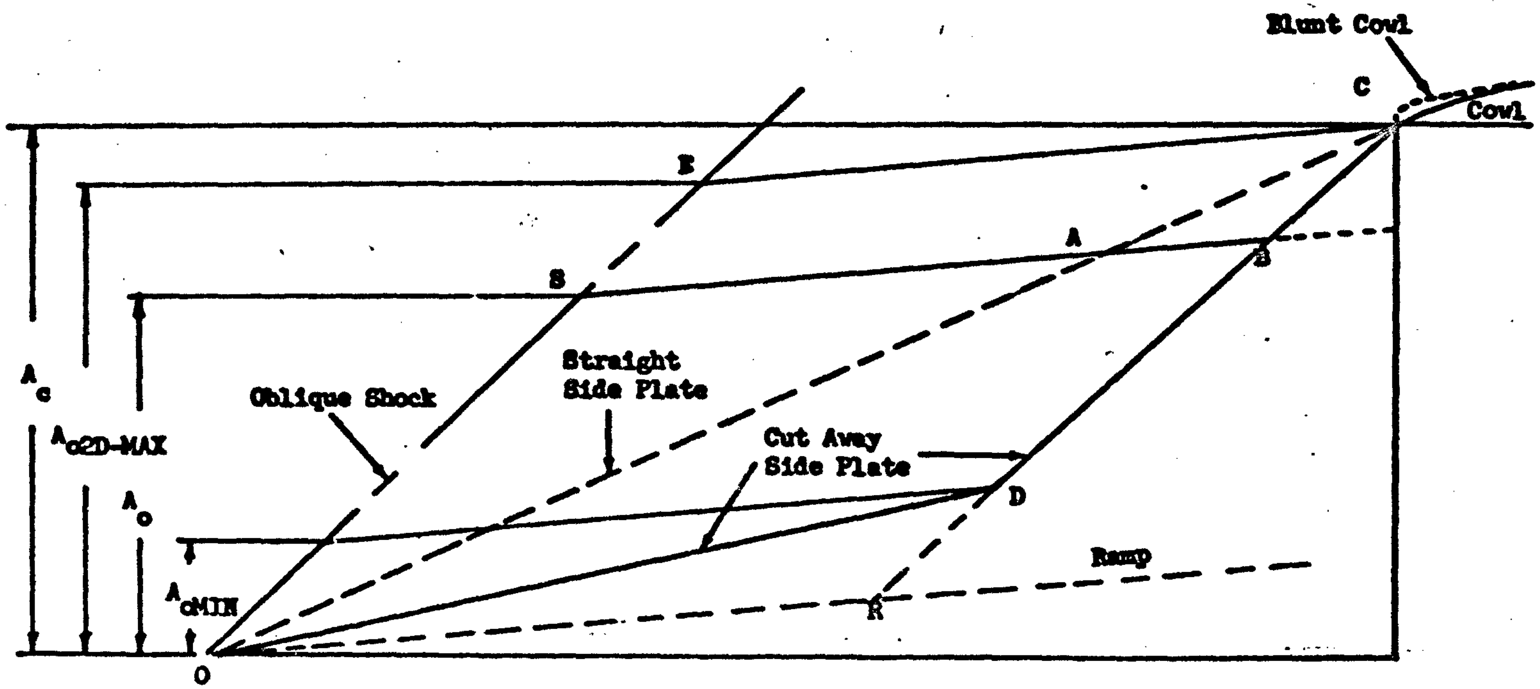


Figure 44. Inlet Nomenclature

APPENDIX III

COMPILATION OF DATA PLOTS

Appendix III is an accumulation of plots of data or factors derived from data, figures 45 thru 115 inclusive.

SYM.	CONFIG.	$\alpha°$	$\beta°$	M_0	(A_0/A_c) ref.
○	R1SP1C1	5°	5°	0.69	0.796
△	C2	"	"	"	"
□	C3	"	"	"	"
◇	C4	"	"	"	"
▽	C5	"	"	"	"
▮	C6	"	"	"	"

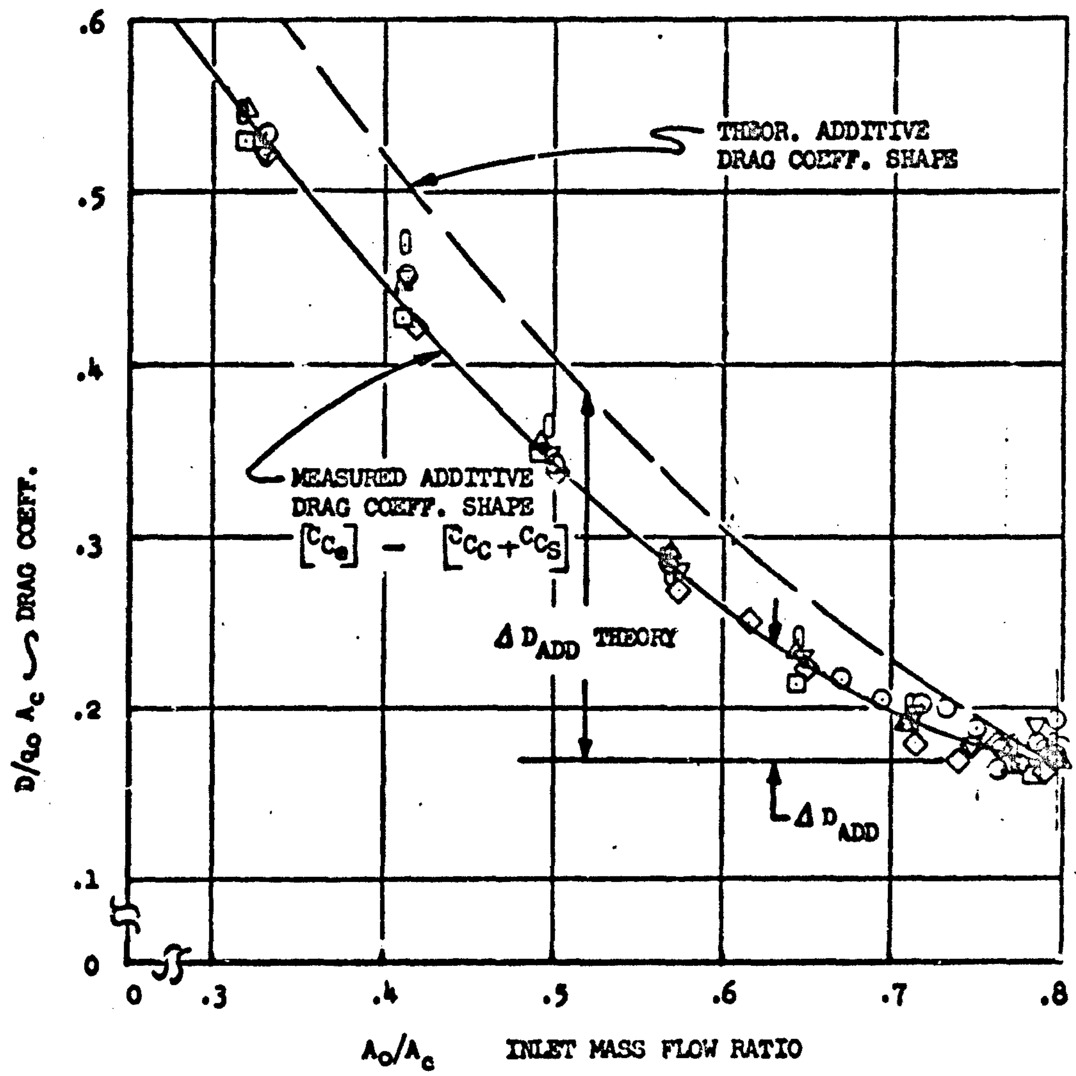


Figure 45. ADDITIVE DRAG COEFF. SHAPES ~ MEASURED vs. THEORY, M_0 = 0.69

SYM.	CONFIG.	$\alpha°$	$\beta°$	M_o	(A_o/A_c) ref.
○	R1SP1C1	5°	5°	0.84	0.796
△	C2	"	"	"	"
□	C3	"	"	"	"
◇	C4	"	"	"	"
▽	C5	"	"	"	"
0	C6	"	"	"	"

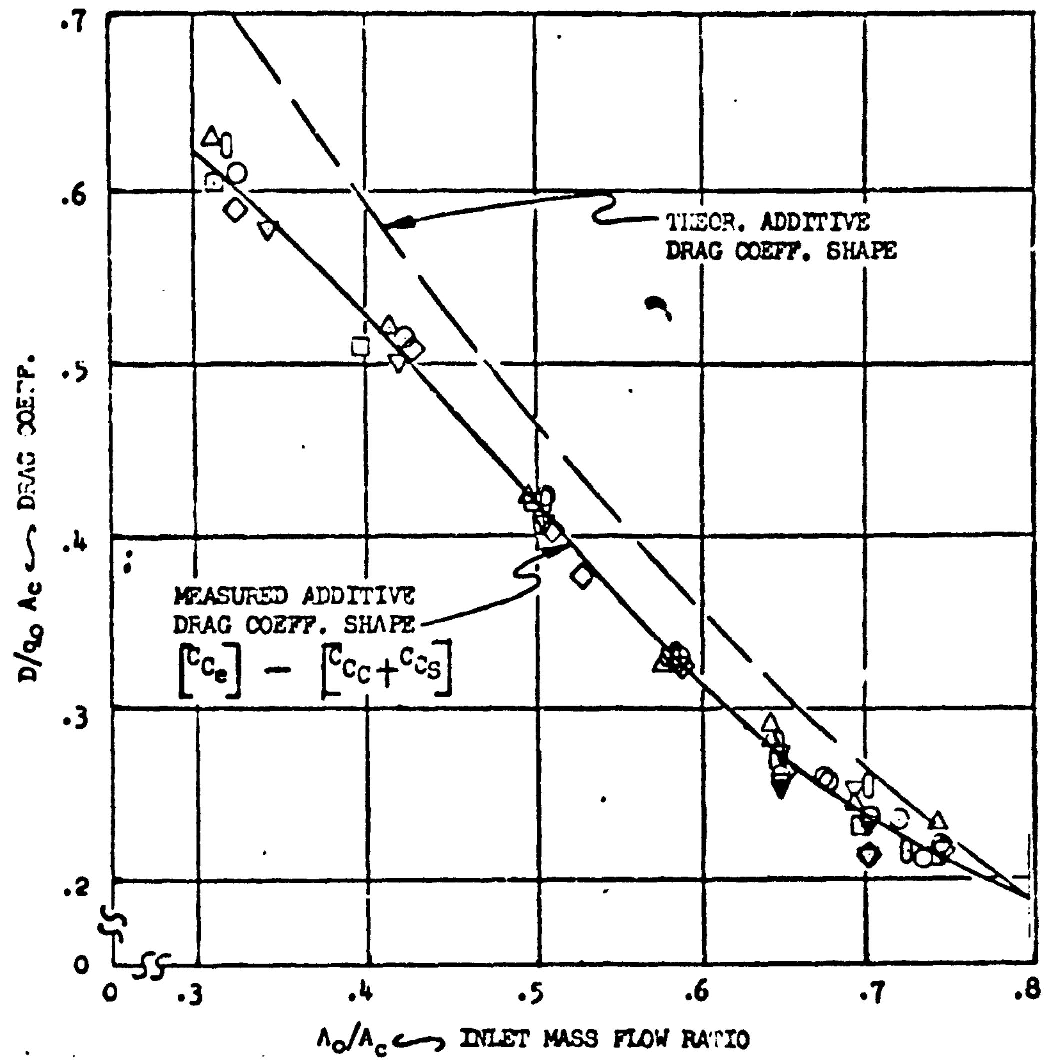


Figure 46. ADDITIVE DRAG COEFF. SHAPES ⟿ MEASURED vs. THEORY, $M_o = 0.84$

SYM.	CONFIG.	$\alpha°$	$\beta°$	M_o	(A_o/A_c) ref.
○	R1SP1C1	5°	5°	1.09	0.796
△	C2	"	"	"	"
□	C3	"	"	"	"
◇	C4	"	"	"	"
▽	C5	"	"	"	"
0	C6	"	"	"	"

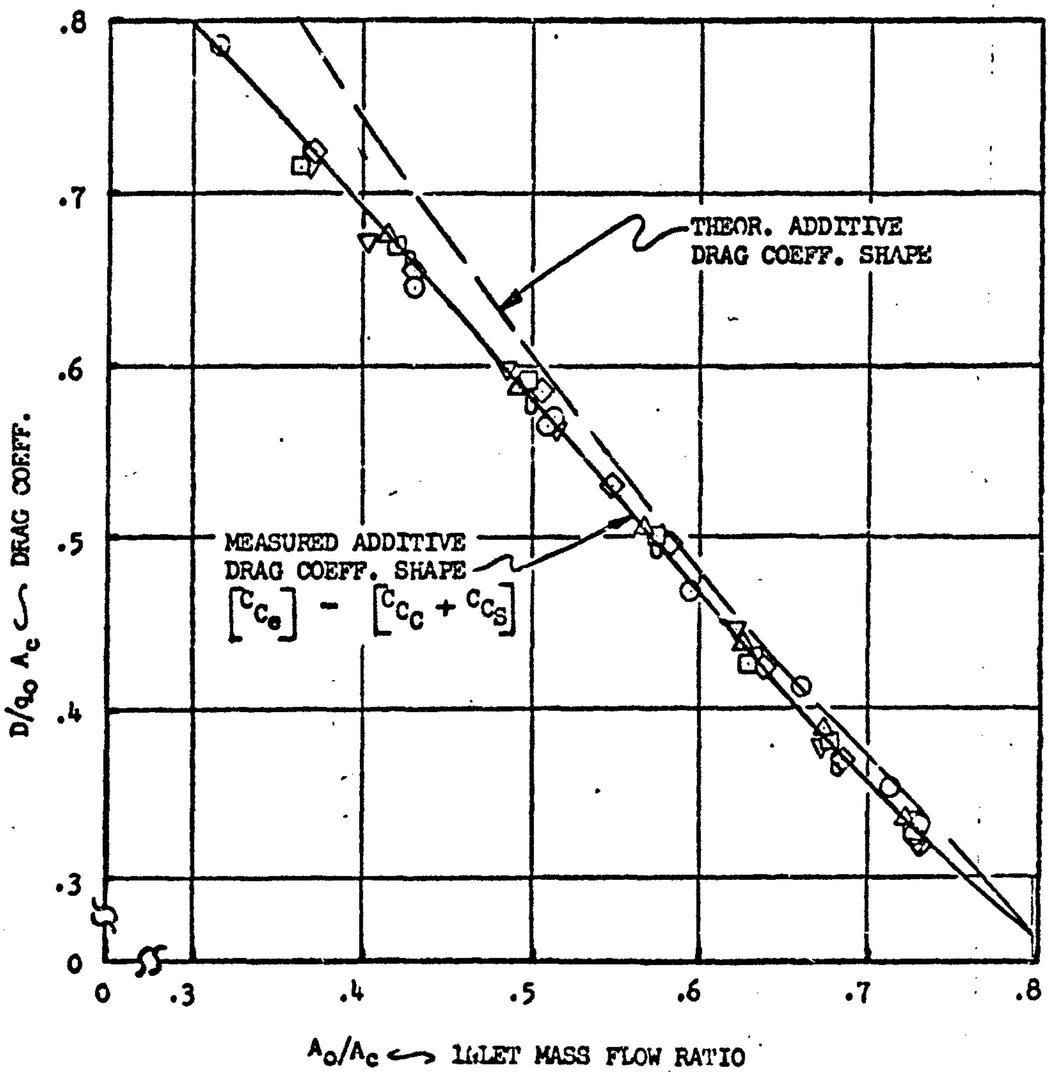


Figure 47. ADDITIVE DRAG COEFF. SHAPES ~ MEASURED vs. THEORY, M_o = 1.09

SYM.	CONFIG.	$\alpha°$	$\beta°$	M_0	(A_0/A_c) ref.
○	R1SP1C1	5°	5°	1.29	0.780
△	C2	"	"	"	"
□	C3	"	"	"	"
◇	C4	"	"	"	"
▽	C5	"	"	"	"
0	C6	"	"	"	"

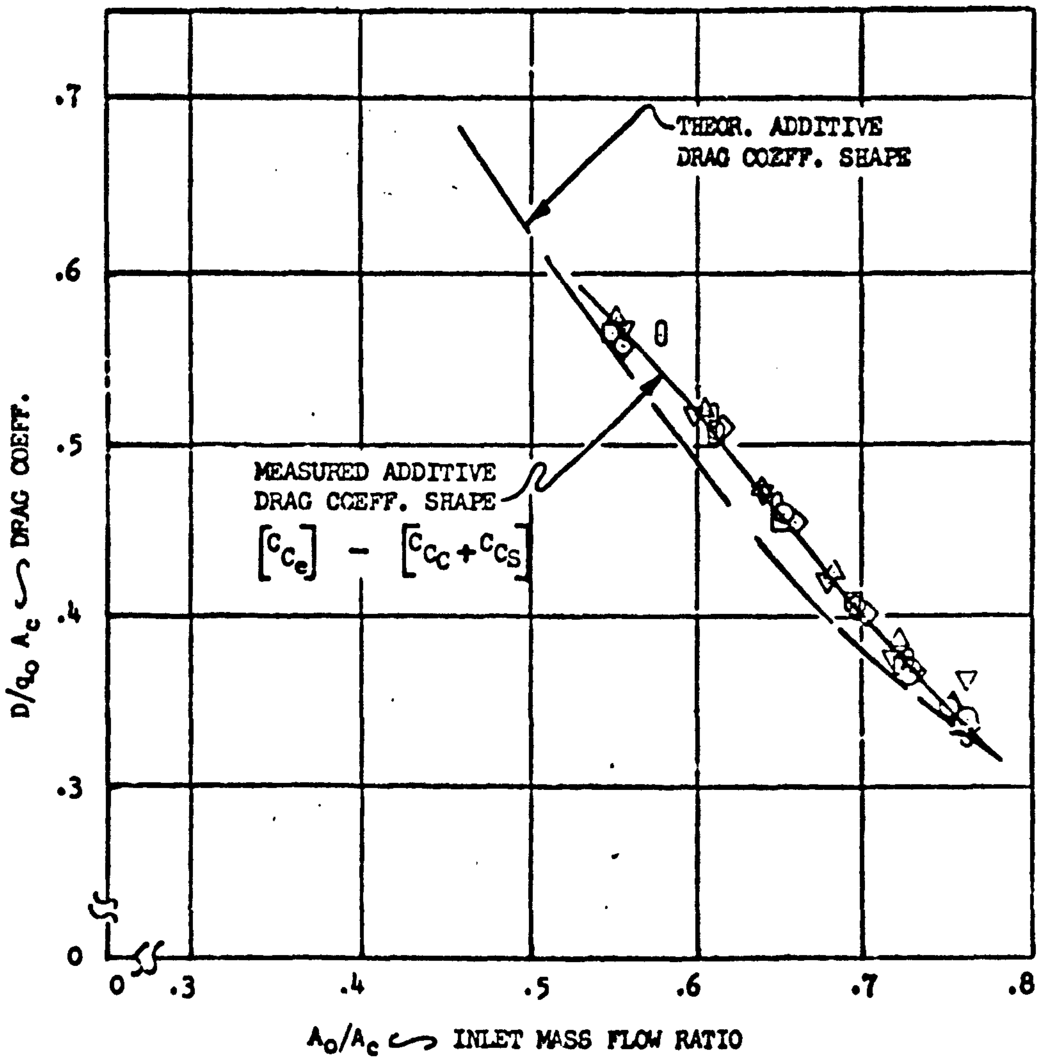


Figure 48. ADDITIVE DRAG COEFF. SHAPES ∽ MEASURED vs. THEORY, M_0 = 1.29

SYM.	CONFIG.	$\alpha°$	$\beta°$	M_o	(A_o/A_c) ref.
○	R1SP1C1	5°	5°	1.39	0.799
△	C2	"	"	"	"
□	C3	"	"	"	"
◇	C4	"	"	"	"
▽	C5	"	"	"	"
▯	C6	"	"	"	"

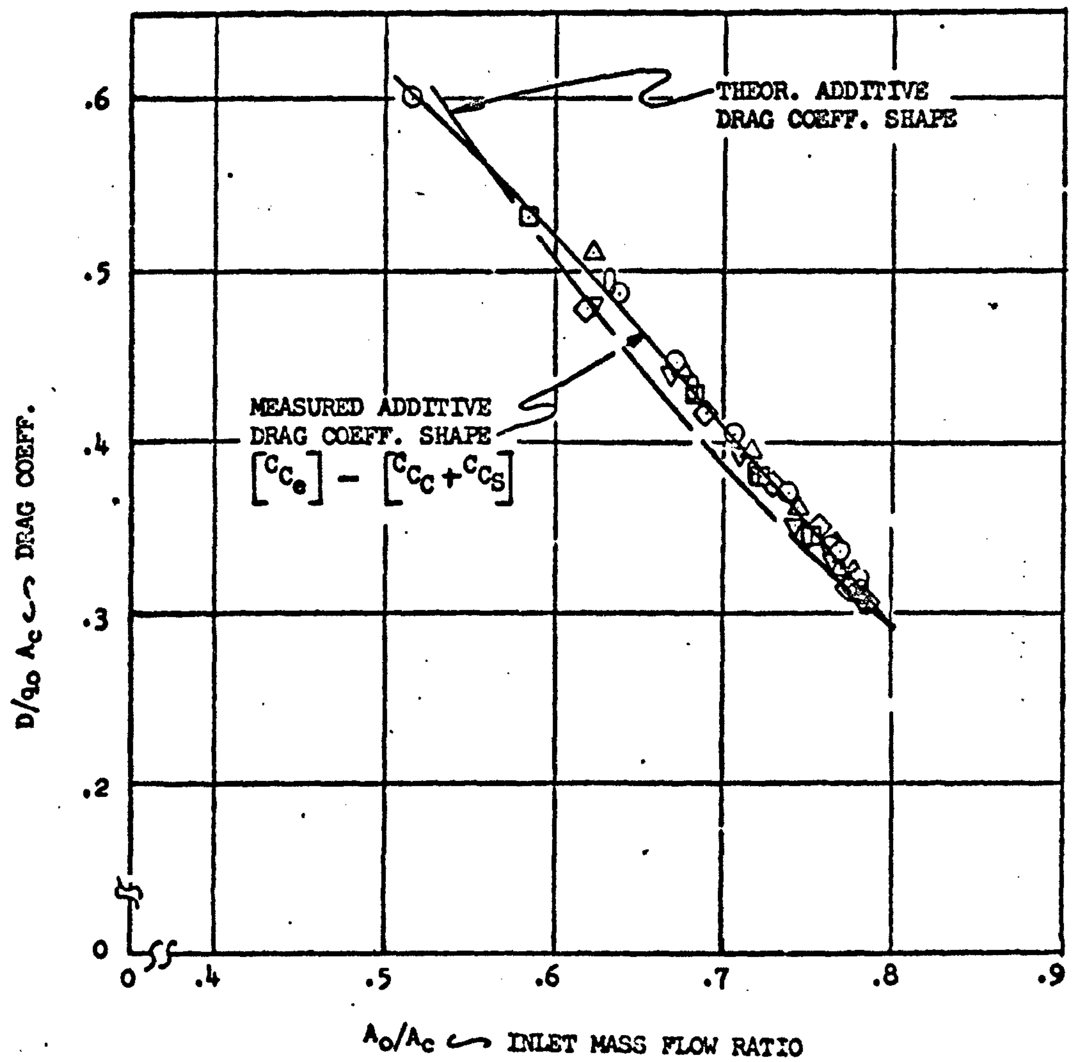


Figure 49. ADDITIVE DRAG COEFF. SHAPES ⟶ MEASURED vs. THEORY, $M_o = 1.39$

SYM	CONFIG.	α^o	β^o	M_o	(A_o/A_c) ref.
○	R1SP1C1	5°	5°	1.69	0.841
▽	C5	"	"	"	"

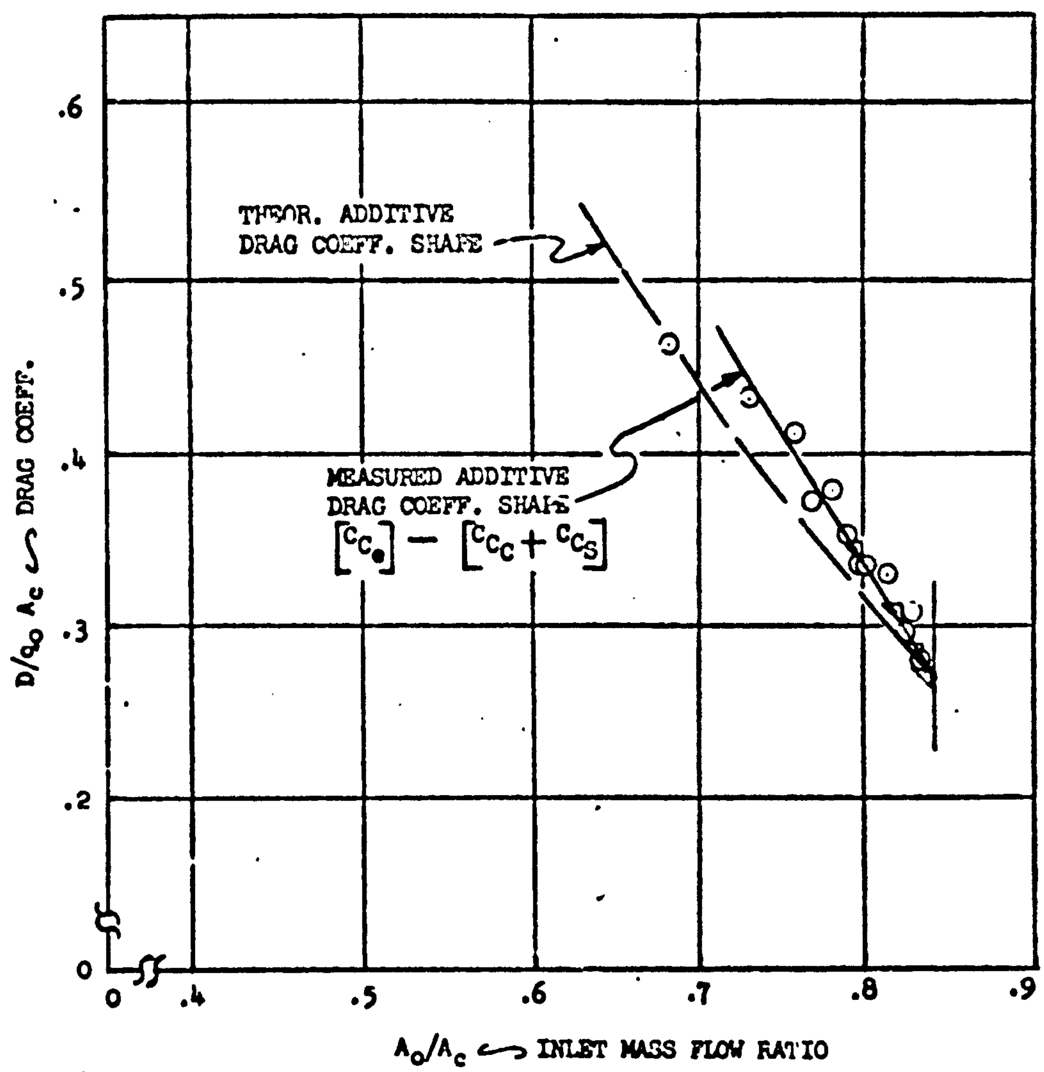


Figure 50. ADDITIVE DRAG COEFF. SHAPES ∽ MEASURED vs. THEORY, M_o = 1.69

NOTE: EACH DRAG CURVE HAS A DIFFERENT ZERO LEVEL (AS INDICATED) TO SPREAD DATA. BASIC SCALE SHOWN FOR C1 ONLY.

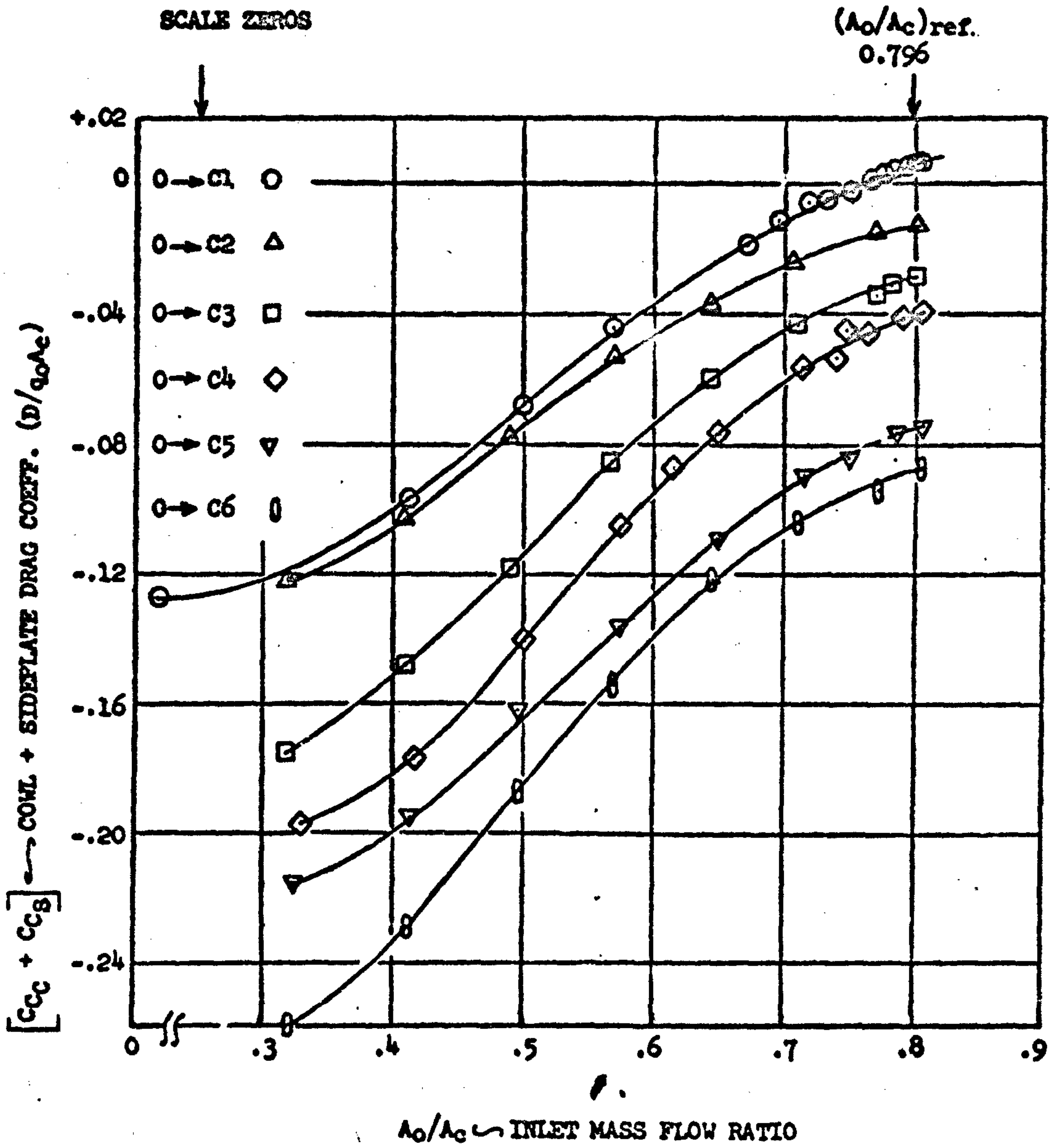


Figure 51. COWL + SIDEPLATE DRAG ∽ R1SP1C1 THRU C6, $\alpha = \beta = 5°$, $M_o = 0.69$

NOTE: EACH DRAG CURVE HAS A DIFFERENT ZERO LEVEL (AS INDICATED) TO SPREAD DATA. BASIC SCALE SHOWN FOR C1 ONLY.

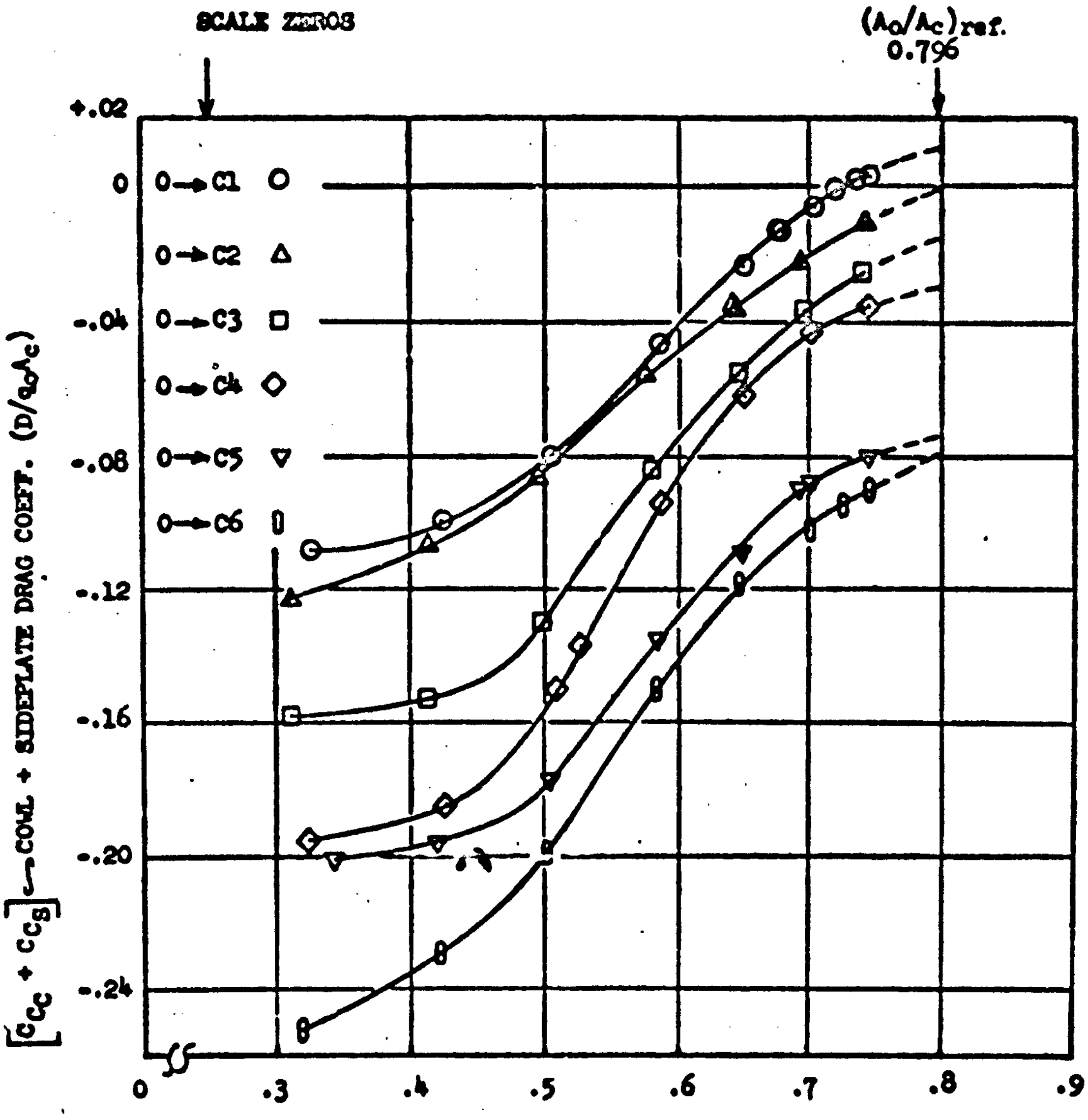


Figure 52. COWL + SIDEPLATE DRAG ~ R1SP1C1 THRU C6, $\alpha=\beta=5^\circ$, $M_o = 0.84$

NOTE: EACH DRAG CURVE HAS A DIFFERENT ZERO LEVEL (AS INDICATED) TO SPREAD DATA. BASIC SCALE SHOWN FOR C1 ONLY.

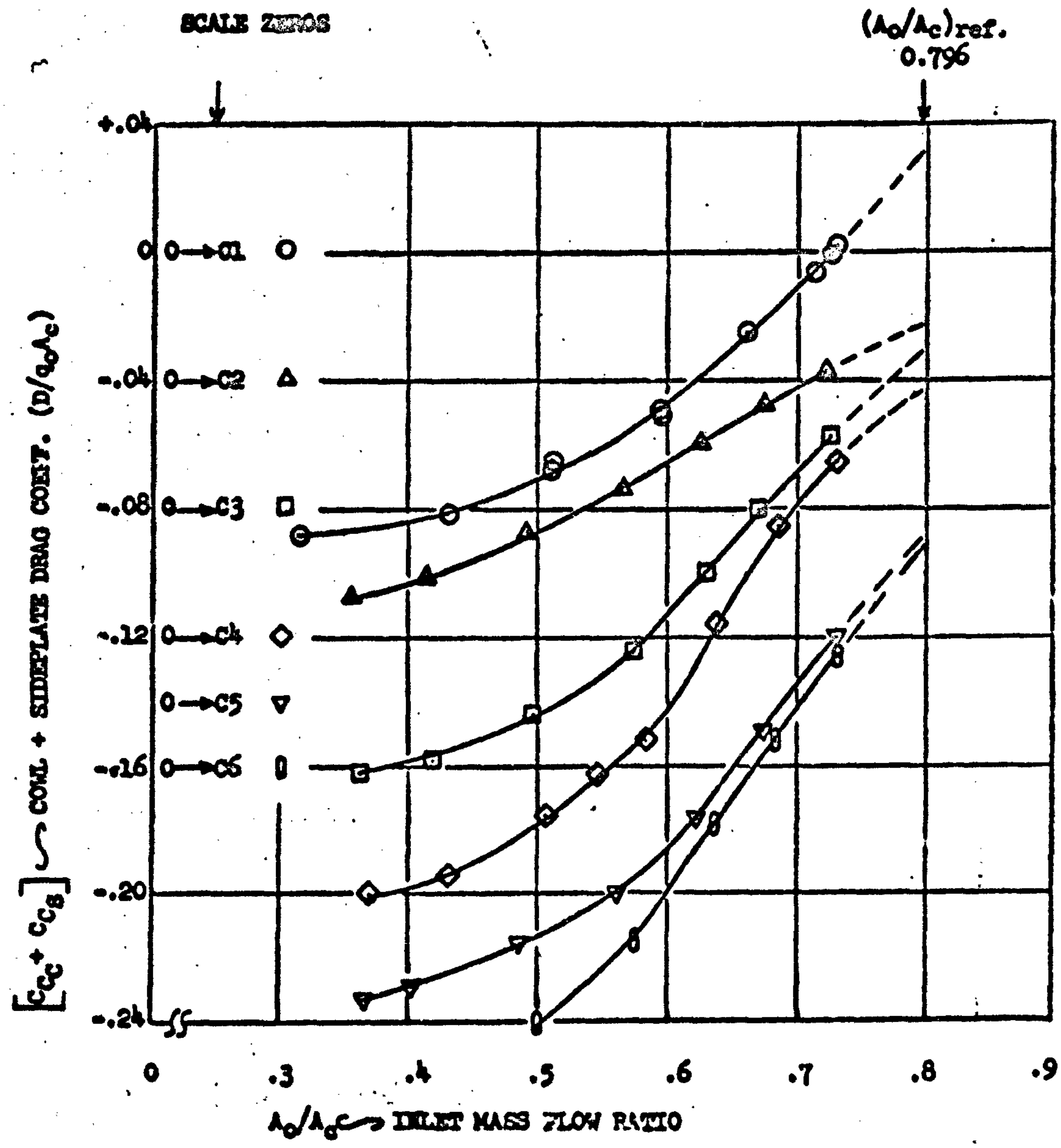


Figure 53. COWL + SIDEPLATE DRAG ~ R1SP1C1 THRU C6, $\alpha = \beta = 5°$, M_o = 1.09

NOTE: EACH DRAG CURVE HAS A DIFFERENT ZERO LEVEL (AS INDICATED) TO SPREAD DATA. BASIC SCALE SHOWN FOR C1 ONLY.

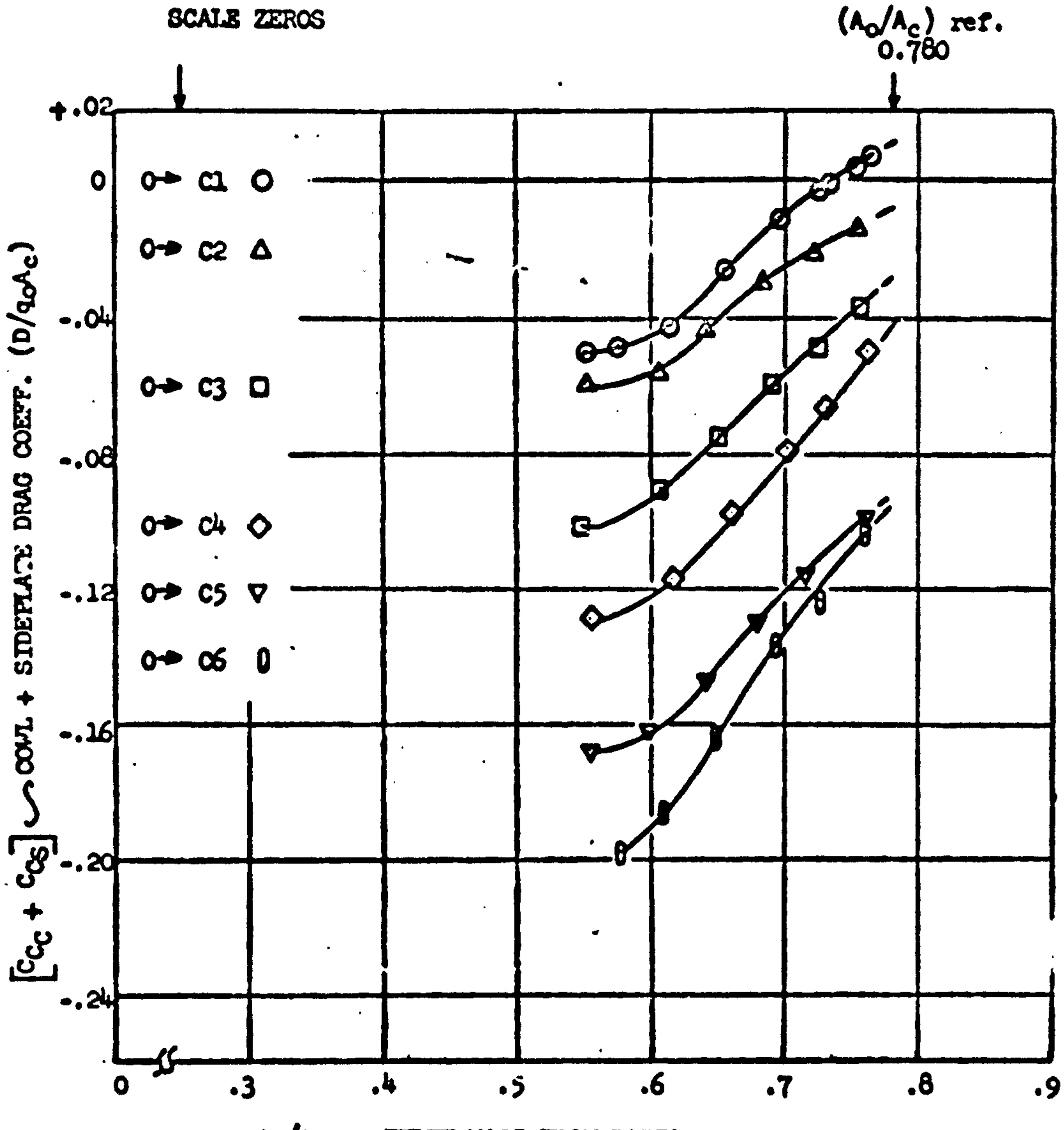


Figure 54. COWL + SIDEPLATE DRAG ~ R1SP1C1 THRU C6, $\alpha = \beta = 5^\circ$, $M_o = 1.29$

NOTE: EACH DRAG CURVE HAS A DIFFERENT ZERO LEVEL (AS INDICATED) TO SPREAD DATA. BASIC SCALE SHOWN FOR C1 ONLY.

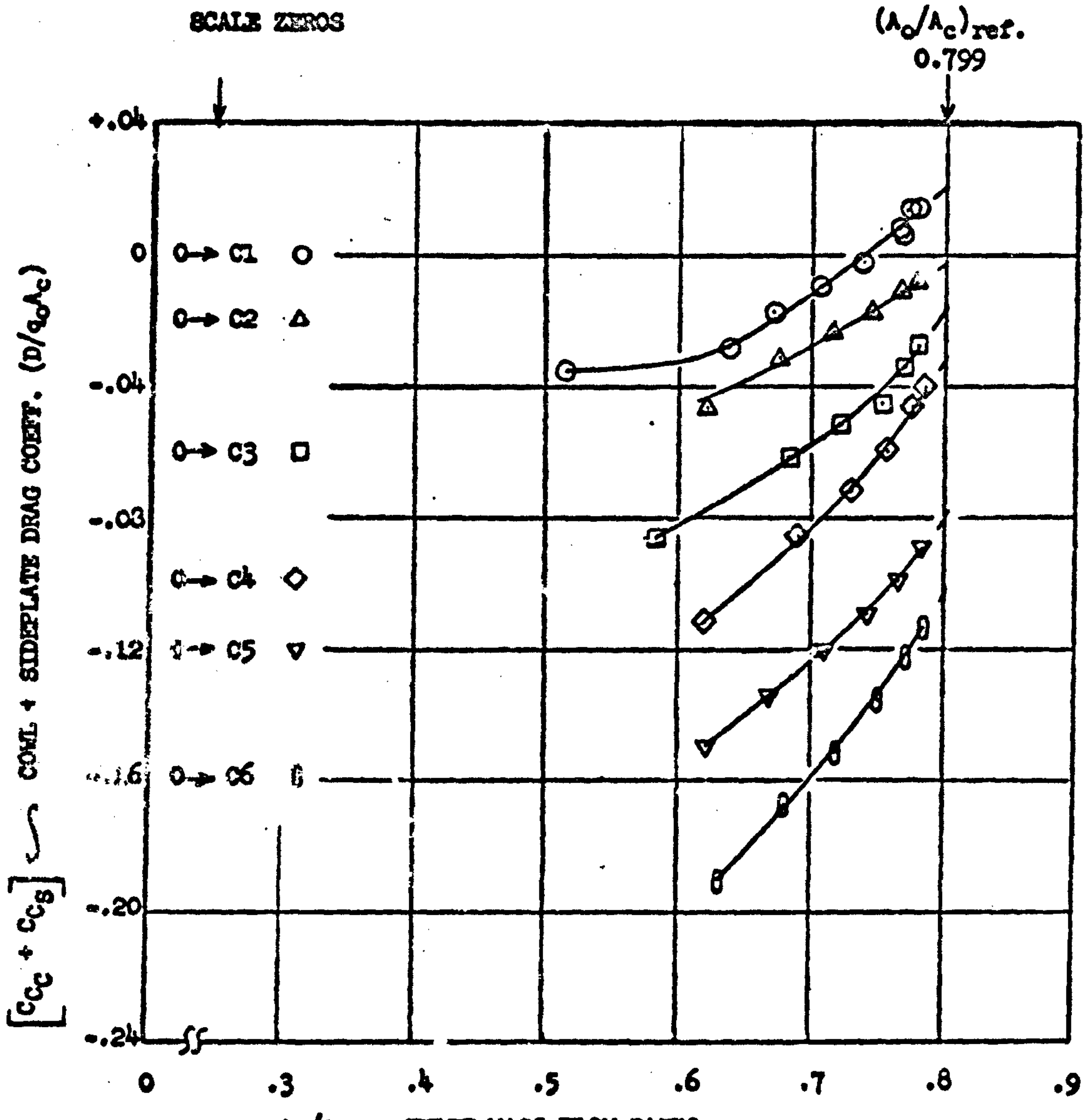


Figure 55. COWL + SIDEPLATE DRAG ∽ R1S-1C1 THRU C6, $\alpha = \beta = 5^\circ$, $M_o = 1.39$

CONFIG.	α°	β°	M_0	(A_0/A_c) ref.
R1SP1C1	5°	5°	0.69	0.796
C2	"	"	"	"
C3	"	"	"	"
C4	"	"	"	"
C5	"	"	"	"
C6	"	"	"	"

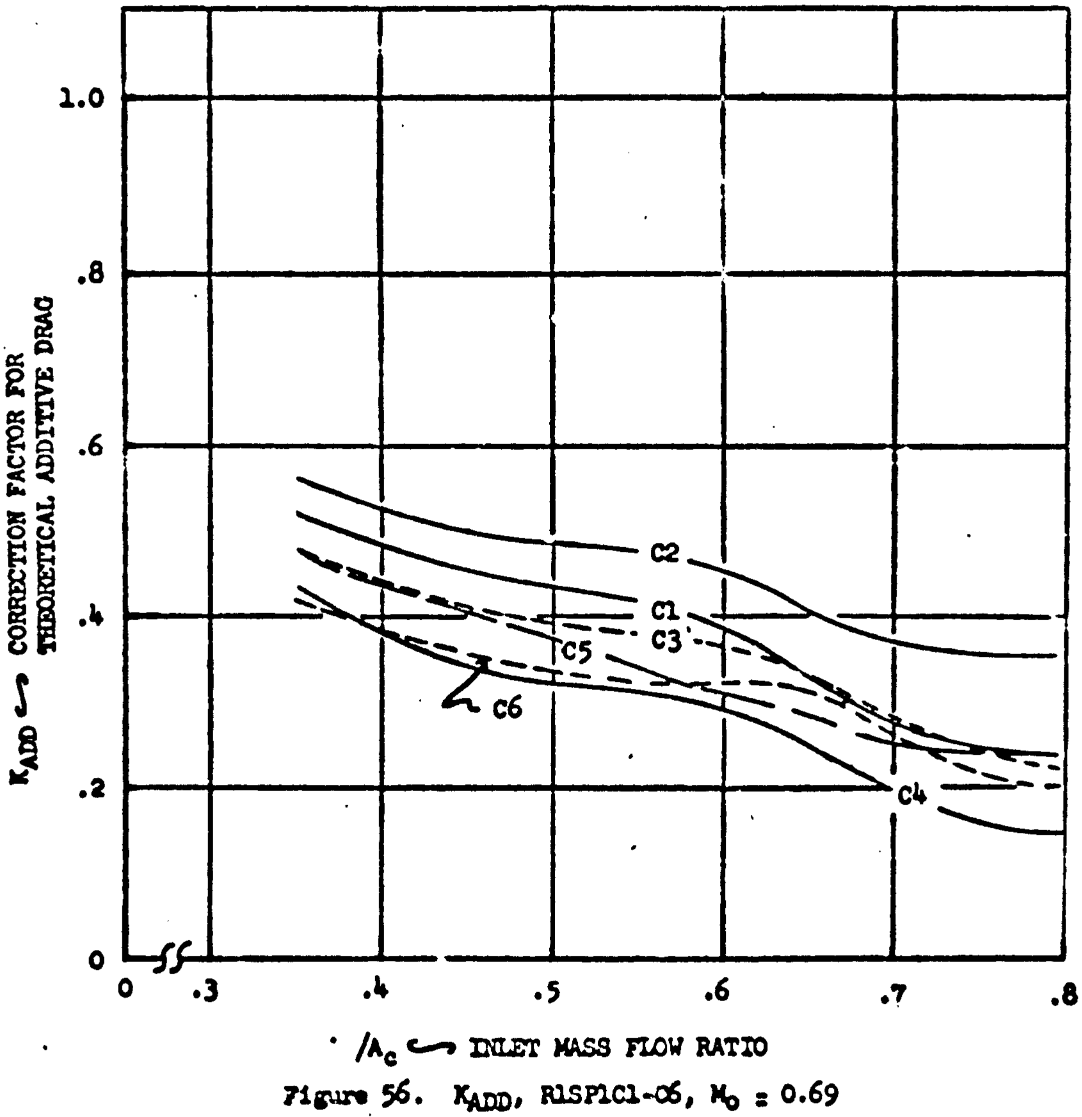


Figure 56. K_{ADD}, R1SP1C1-C6, M_0 = 0.69

CONFIG.	$\alpha°$	$\beta°$	M_o	(A_o/A_c) ref.
R1SP1C1	5°	9°	0.69	0.715

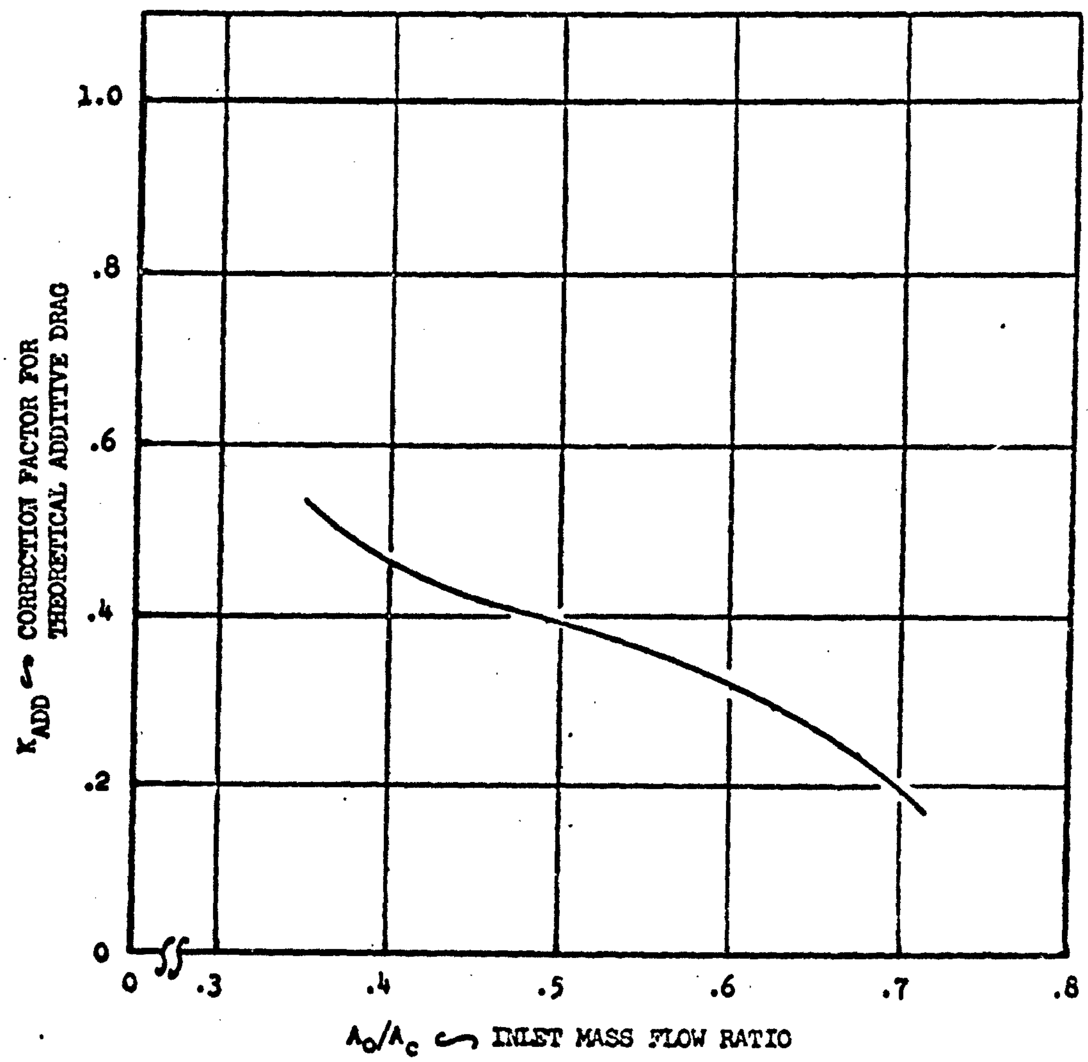


Figure 57. K_{ADD}, R1SP1C1, M_o = 0.69

CONFIG.	$\alpha°$	$\beta°$	M_o	(A_o/A_c) ref.
R1SP1C1	5°	12°	0.69	0.715

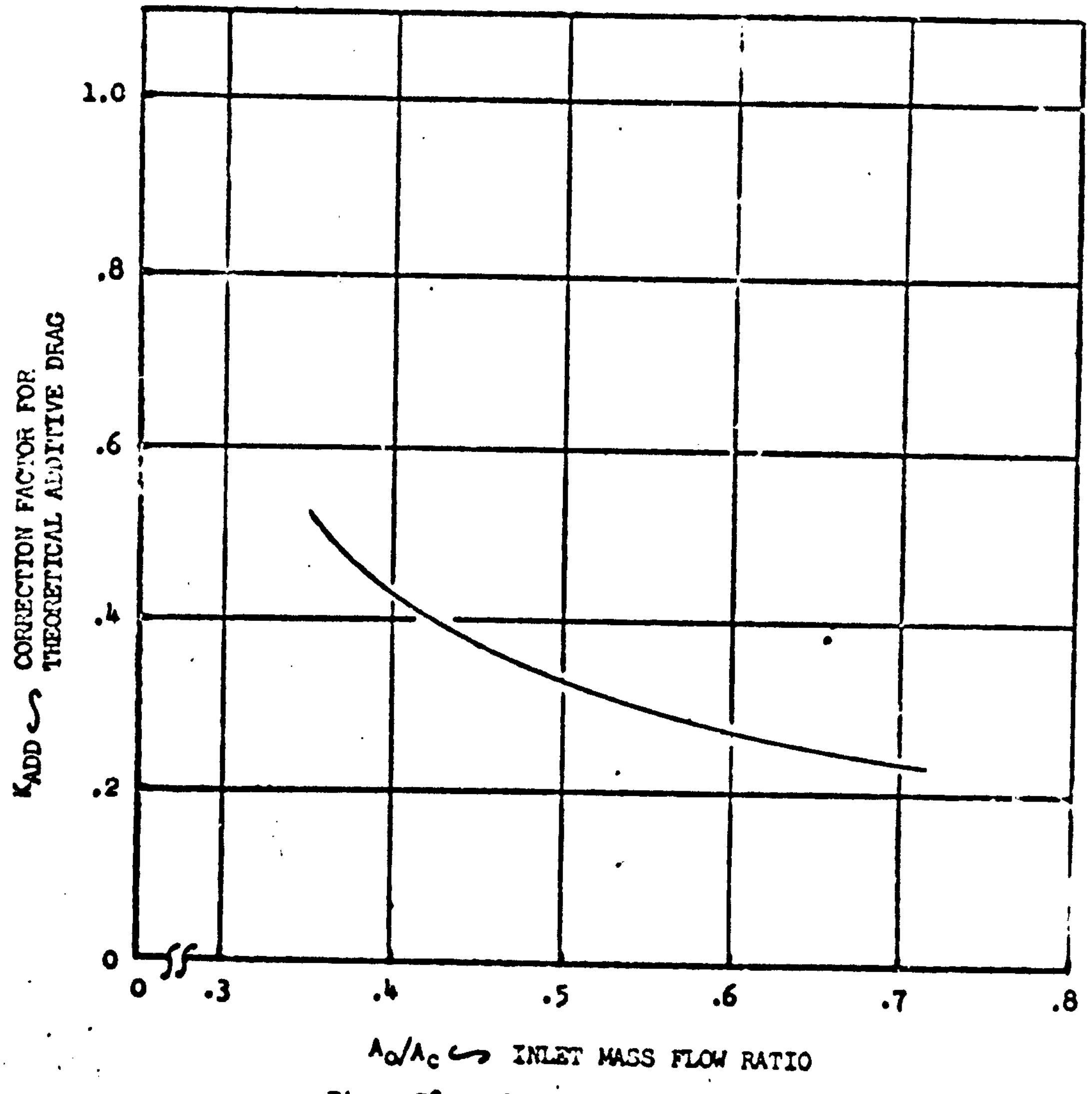


Figure 58. K_{ADD}, R1SP1C1, $M_o = 0.69$

CONFIG.	$\alpha°$	$\beta°$	M_0	(A_0/A_c) ref.
R1SP2C1	5°	5°	0.69	0.796

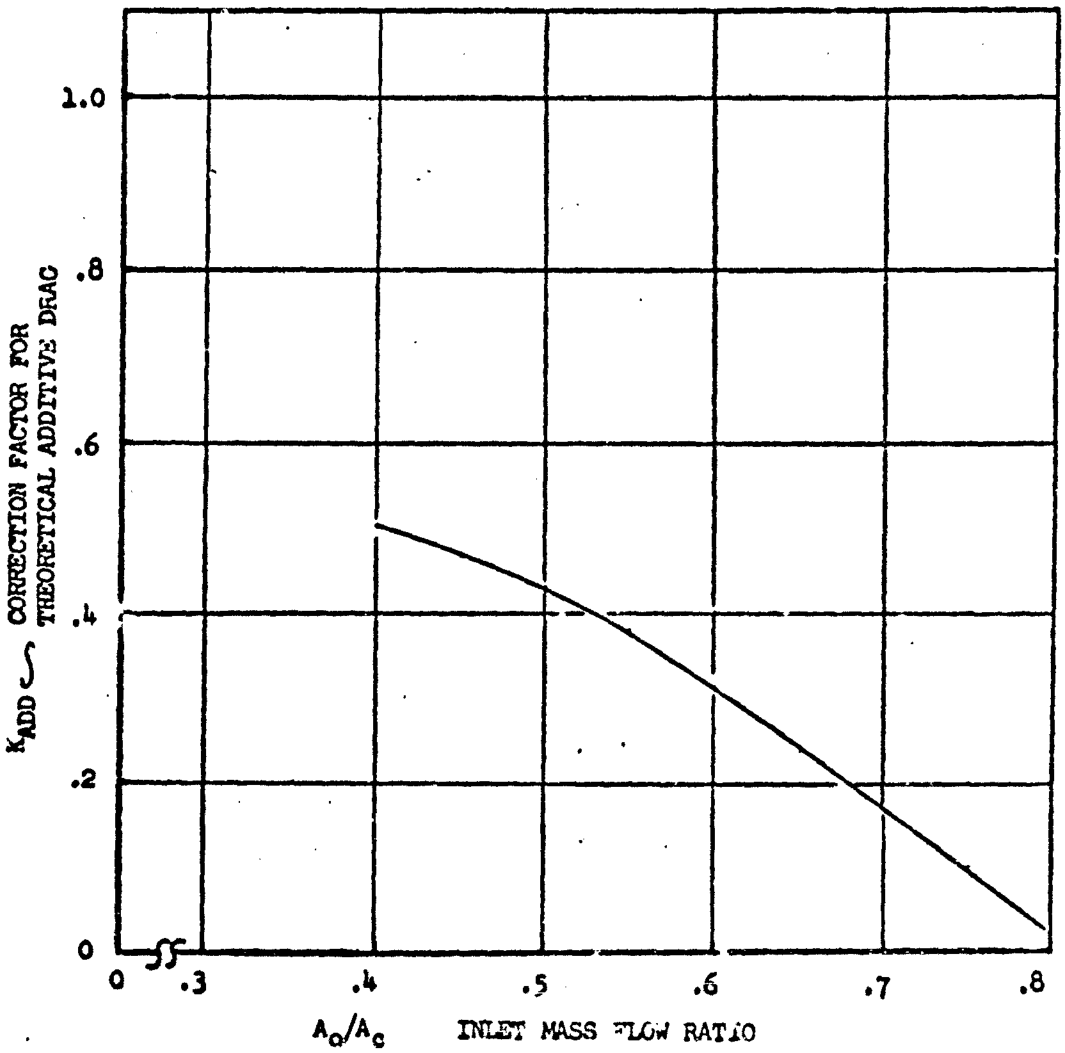


Figure 59. K_{ADD}, R1SP2C1, M_0 = 0.69

CONFIG.	$\alpha°$	$\beta°$	M_0	(A_0/A_c) ref.
R1SP3C1	5°	5°	0.71	0.796

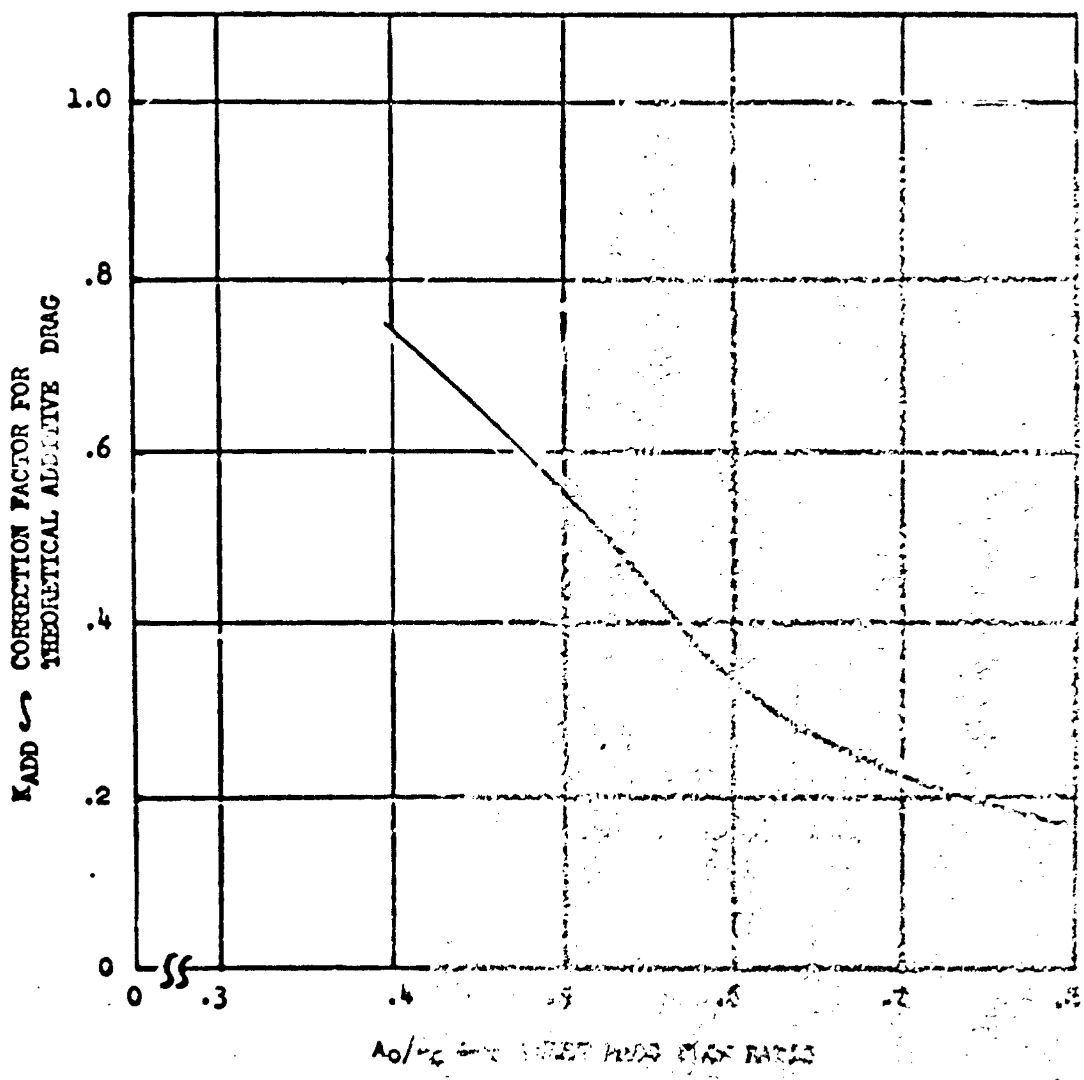


Figure 60. [illegible]

CONFIG.	$\alpha°$	$\beta°$	Mo	(A_o/A_c) ref.
R?SP1C1	7°	7°	0.71	0.713

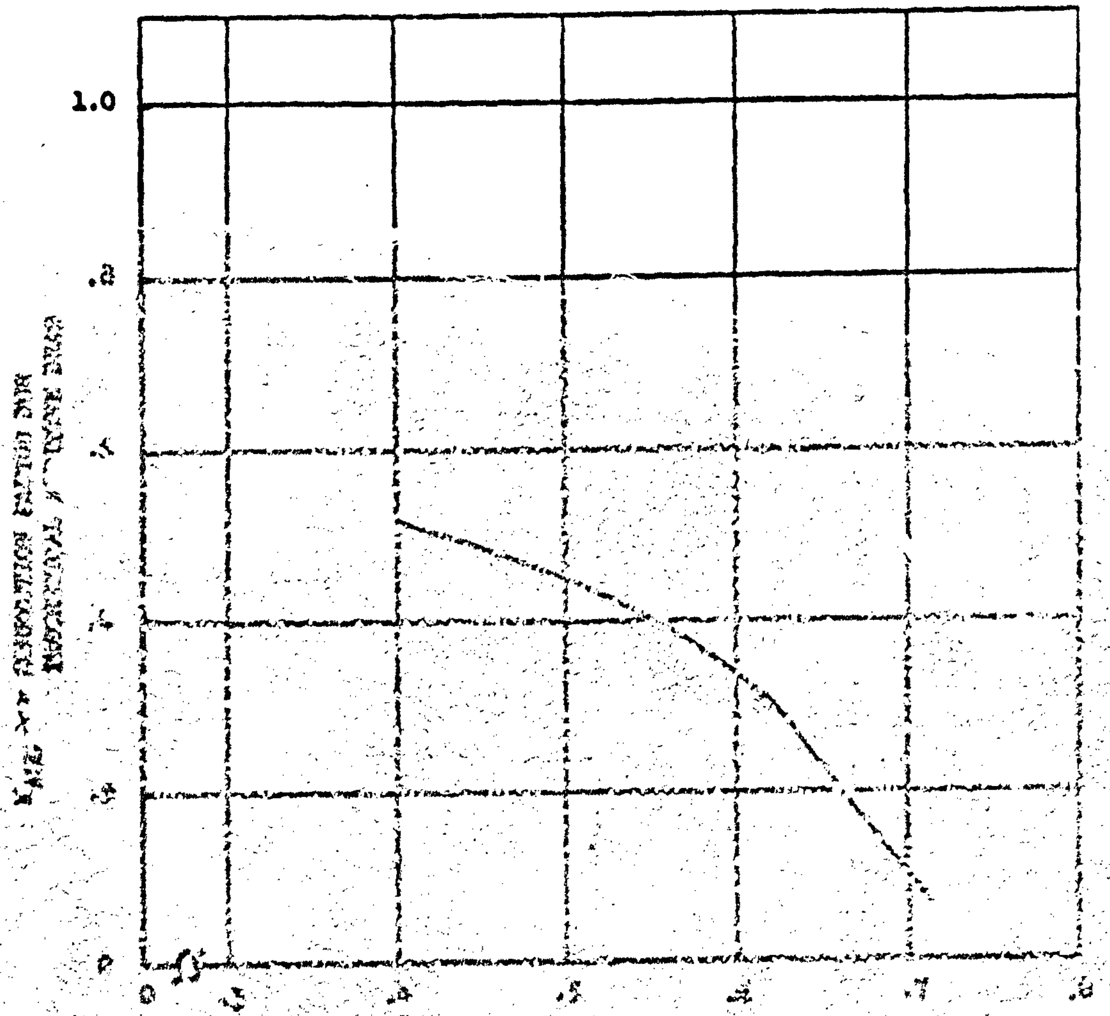
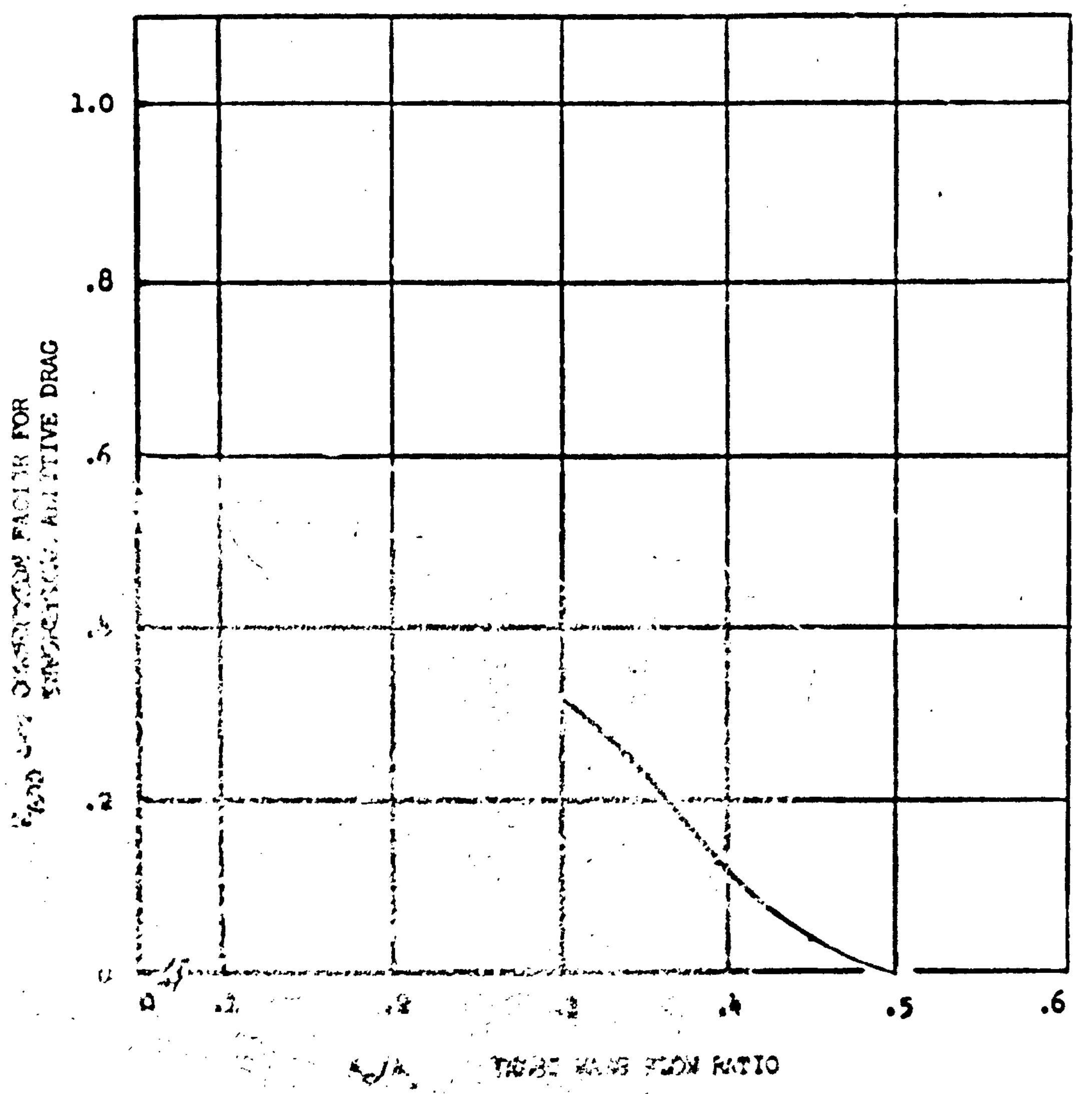


Figure 6[illegible]. K_{ADD}, [illegible], Mo = [illegible]

CONFIG.	$\alpha°$	$\beta°$	M_0	(A_0/A_c) ref.
R3SP1C1	12°	12°	0.71	0.50



[illegible], M_0 = 0.71

CONFIG.	$\alpha°$	$\beta°$	M_0	$(A_0/A_c)_{ref.}$
R4SP4C1	5°	5°	0.71	0.852
C6	"	"	"	"

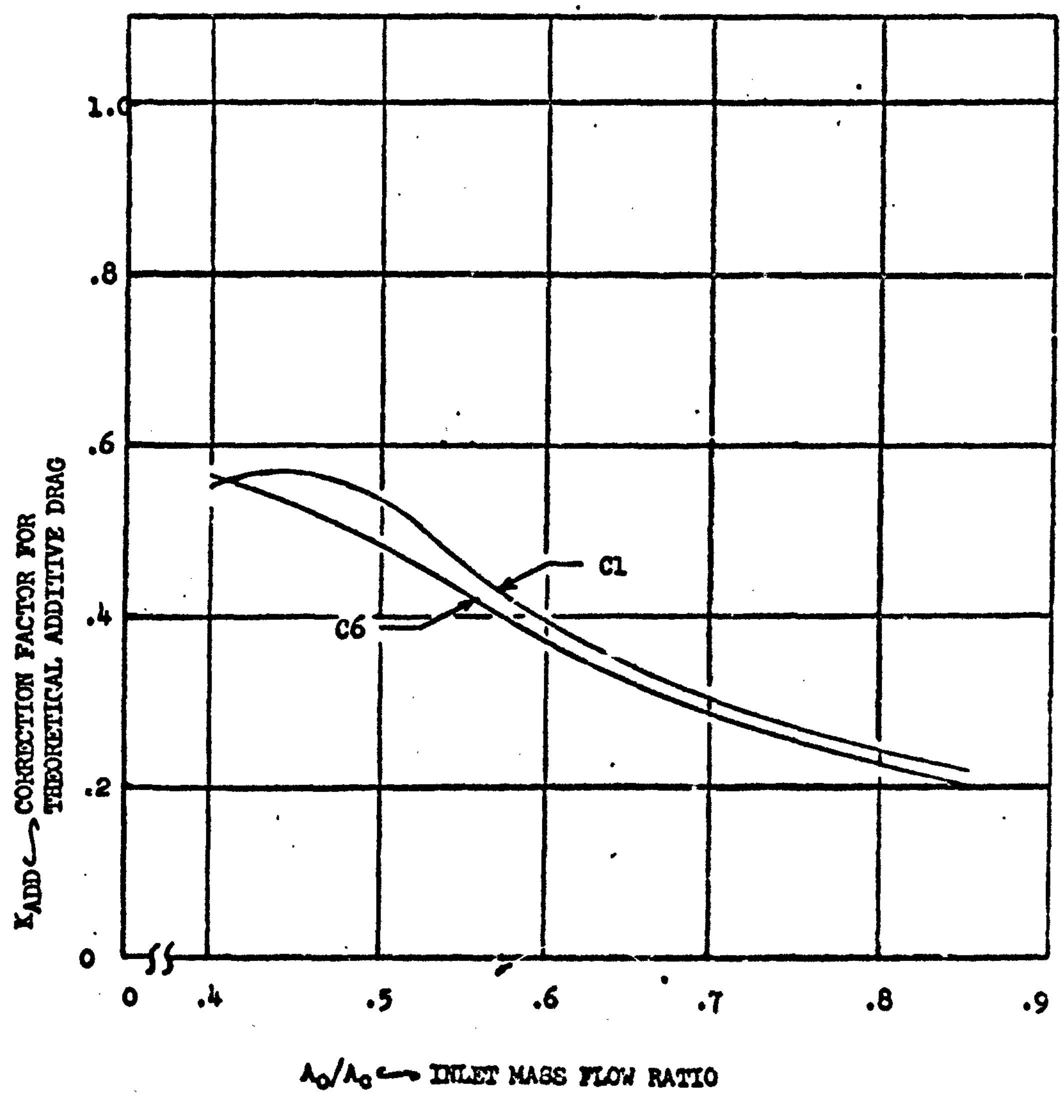


Figure 63. K_{ADD}, R4SP4C1, C6, M_0 = 0.71

CONFIG.	$\alpha°$	$\beta°$	M_0	(A_0/A_c) ref.
R1SP1C1	5°	5°	0.84	0.796
C2	"	"	"	"
C3	"	"	"	"
C4	"	"	"	"
C5	"	"	"	"
C6	"	"	"	"

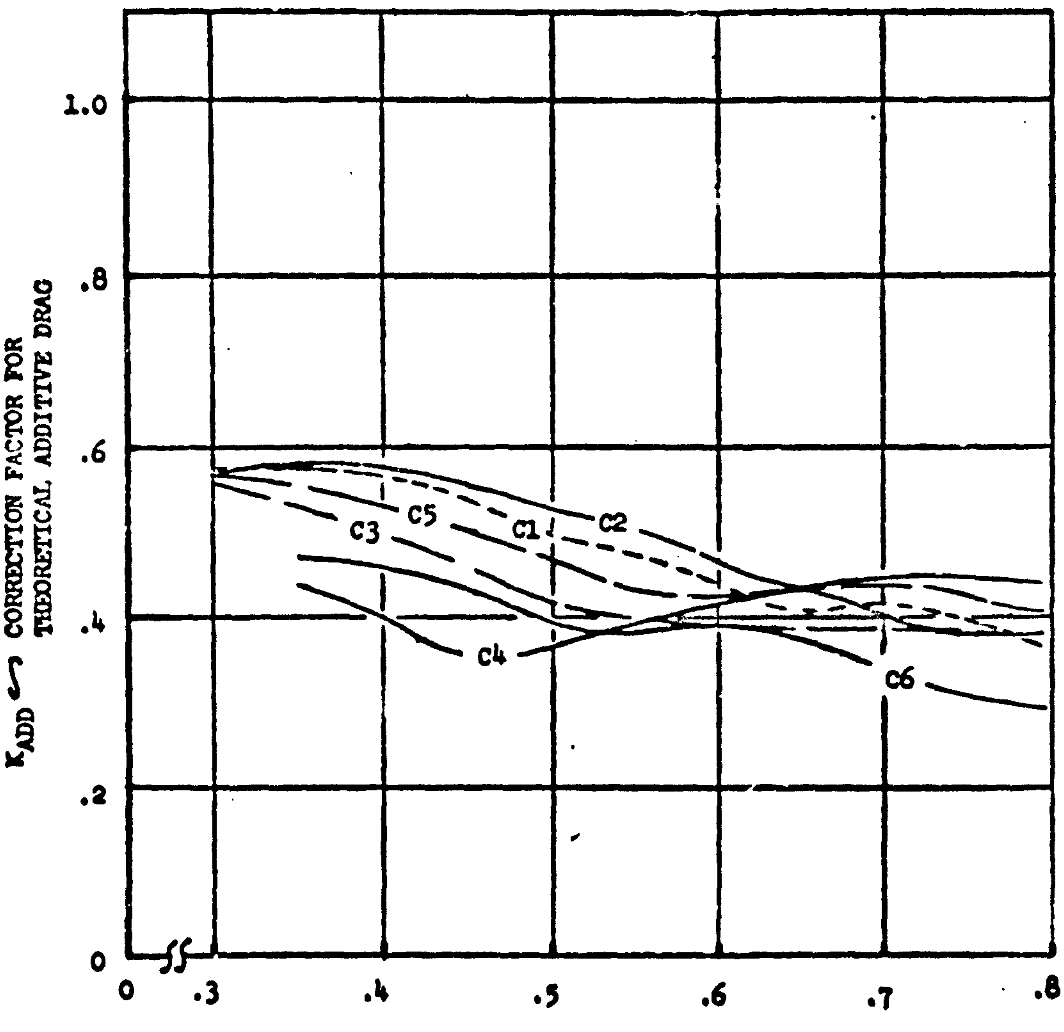


Figure 64. K_{ADD}, R1SP1C1-C6, M_0 = 0.84

CONFIG.	$\alpha°$	$\beta°$	M_o	(A_o/A_c) ref.
R1SP1C1	5°	9°	0.84	0.715

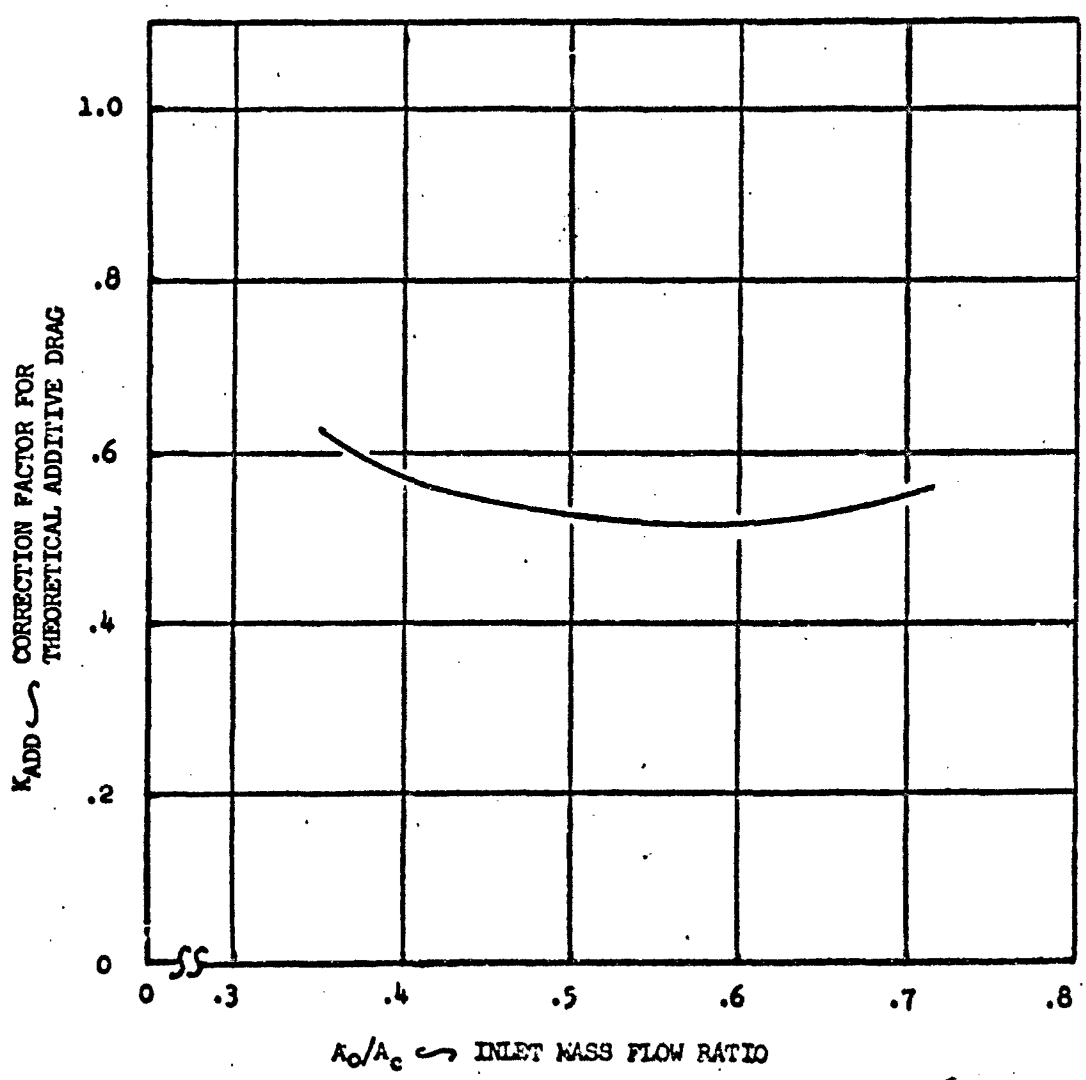


Figure 65. K_{ADD}, R1SP1C1, $M_o = 0.84$

CONFIG.	$\alpha°$	$\beta°$	K_D	(A_0/A_2) ref.
R1SP1C1	5°	12°	[illegible]	[illegible]

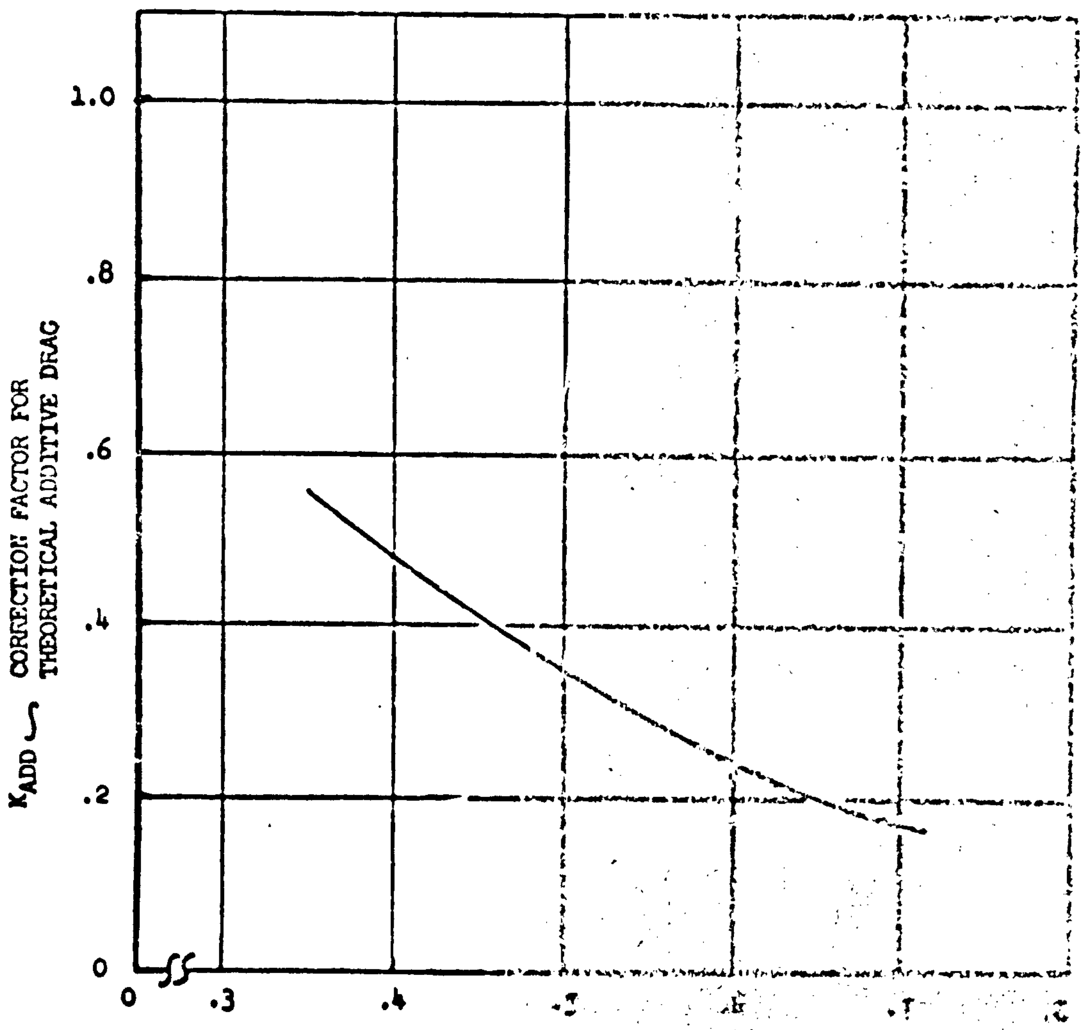
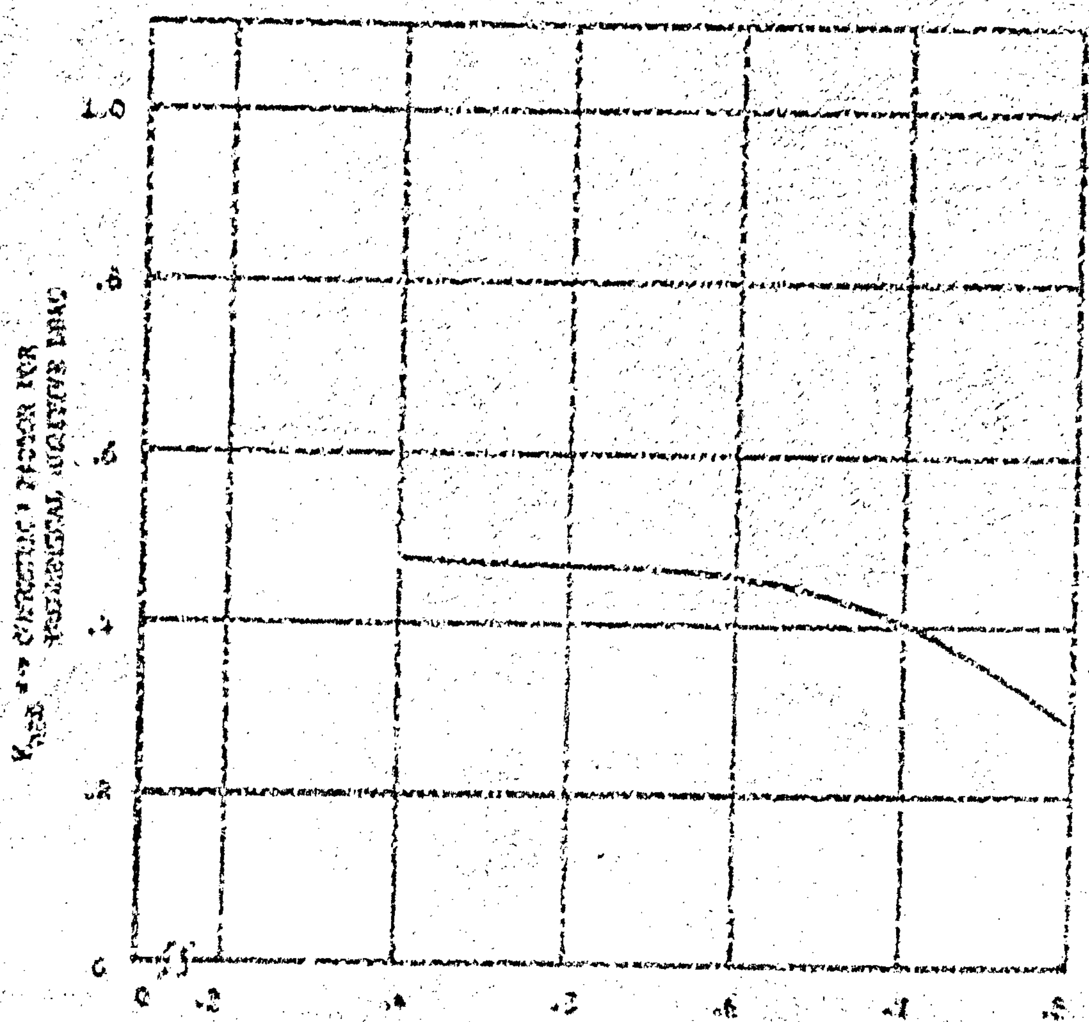


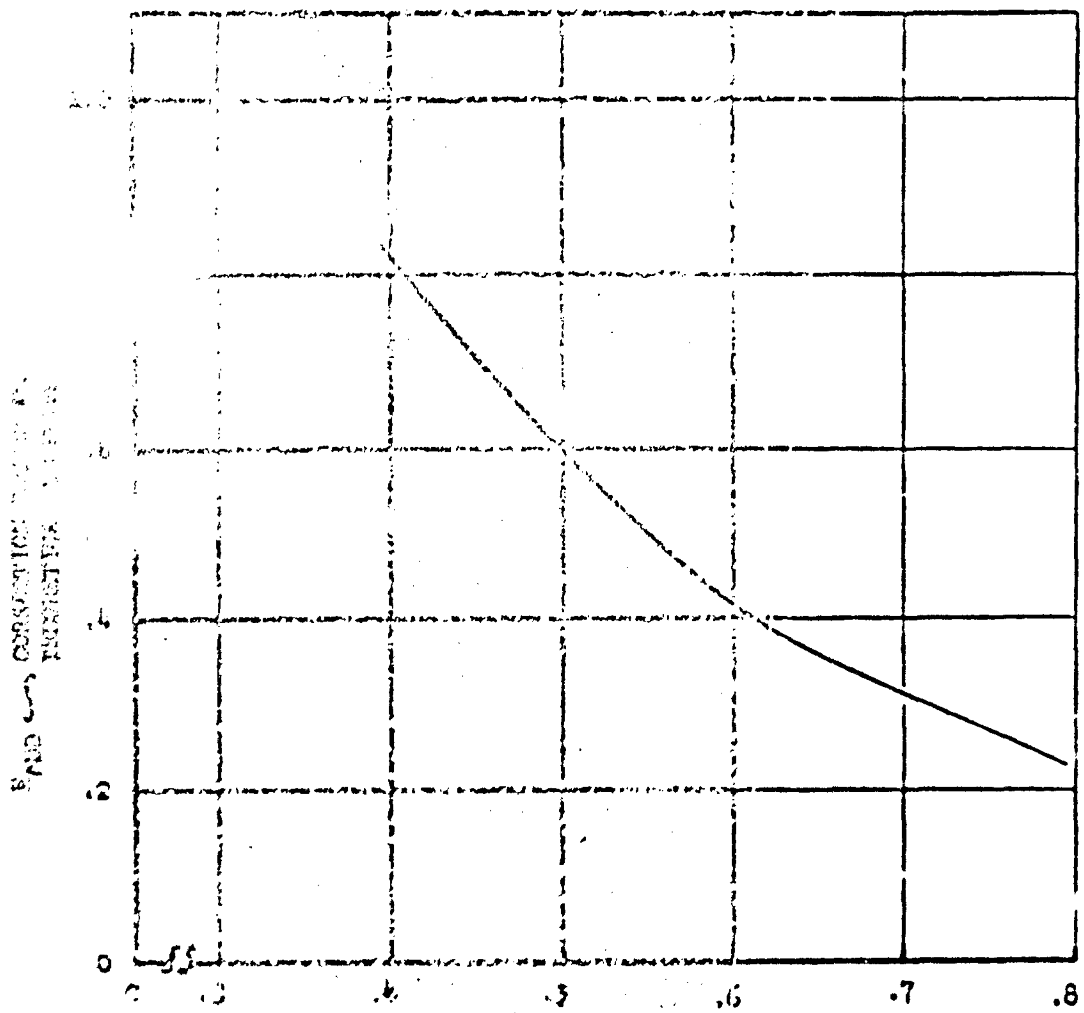
Figure 66. [illegible]

CONFIG.	$\alpha°$	$\beta°$	M_0	(A_0/A_1) crit.
[illegible]	5°	2°	0.9[illegible]	0.735



A_0/A_1 — INLET MASS FLOW RATIO
FIGURE 67. K_{ADD} [illegible], M_0 = 0.[illegible]

CONFIG.	$\delta_1°$	$\delta_2°$	M_0	(A_0/A_c) ref.
[illegible]	[illegible]	5°	0.865	0.796



A_0/A_c — INLET MASS FLOW RATIO

Figure [illegible]. K_{ADD} [illegible], M_0 = 0.865

CONFIG.	$\psi°$	$\beta°$	M_0	(A_0/A_c) ref.
R2SP1C1	7°	7°	0.865	0.713

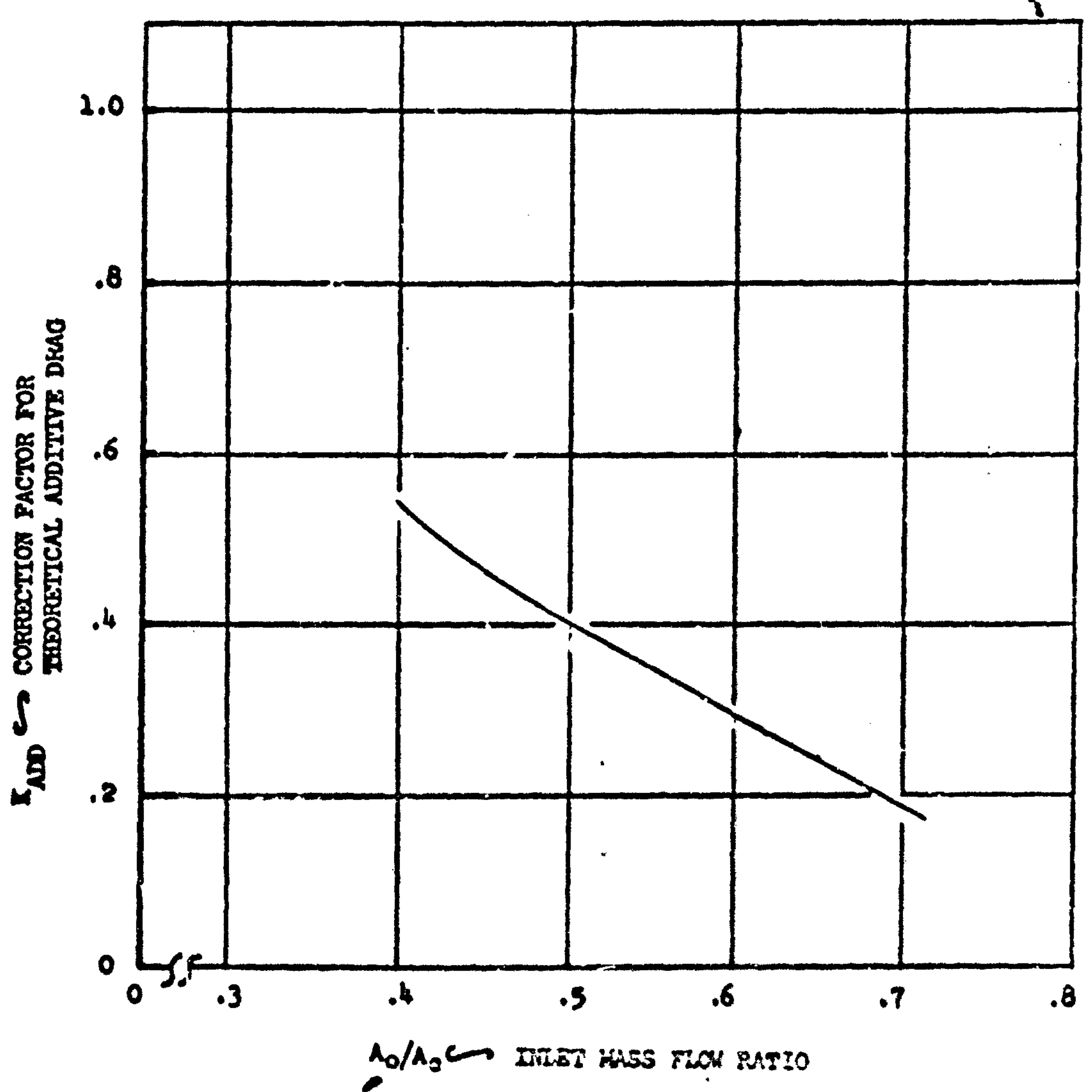


Figure 69. K_{ADD}, R2SP1C1, $M_0 = 0.865$

CONFIG.	$\alpha°$	$\beta°$	Mo	(A_o/A_c) ref.
R3SP1C1	12°	[illegible]	0.865	0.50

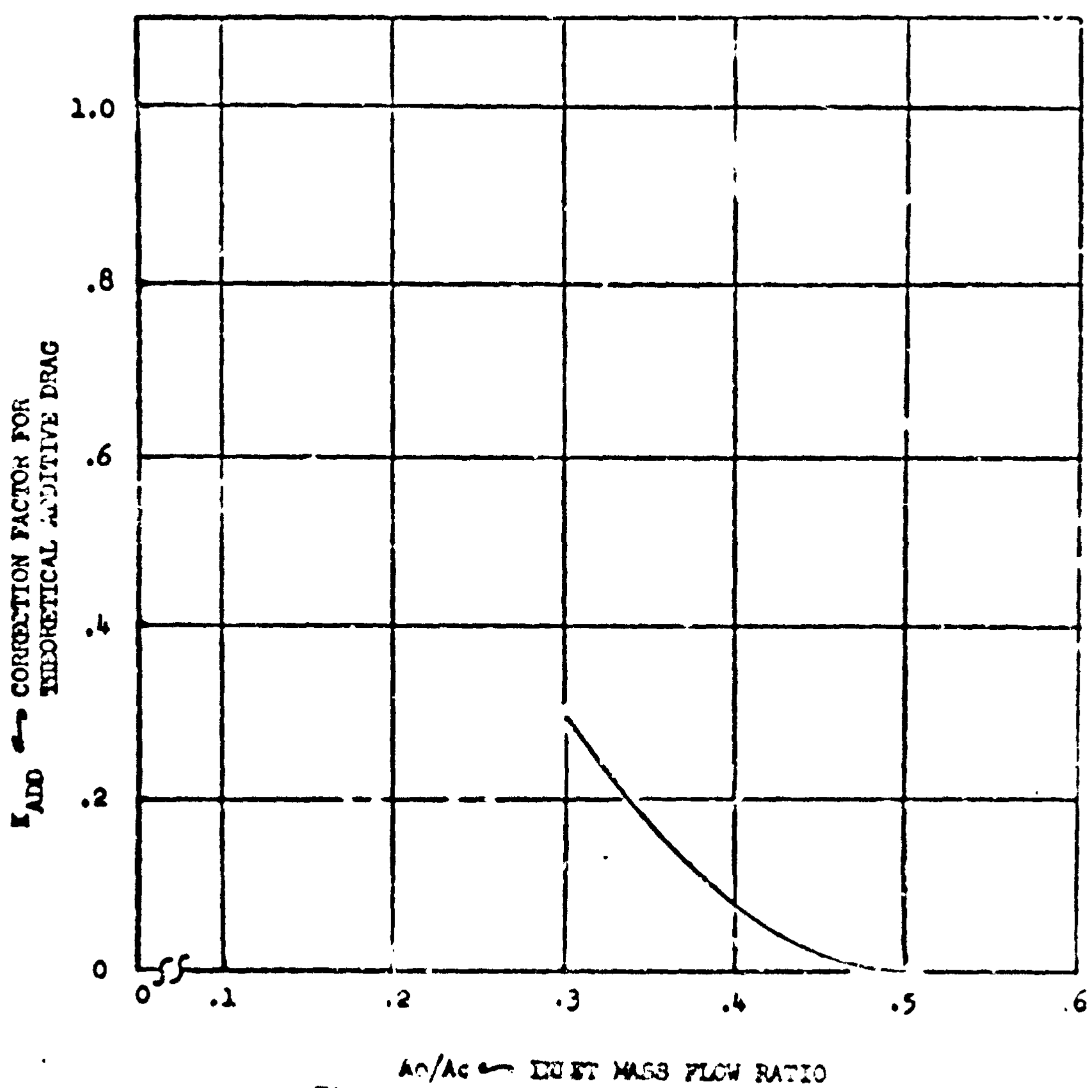


Figure 70. K_{ADD}, R3SP1C1, Mo = 0.865

CONFIG.	$\alpha°$	$\beta°$	M_o	$(A_o/A_c)_{ref.}$
R4SP4C1	5°	5°	0.865	0.852
C6	"	"	"	"

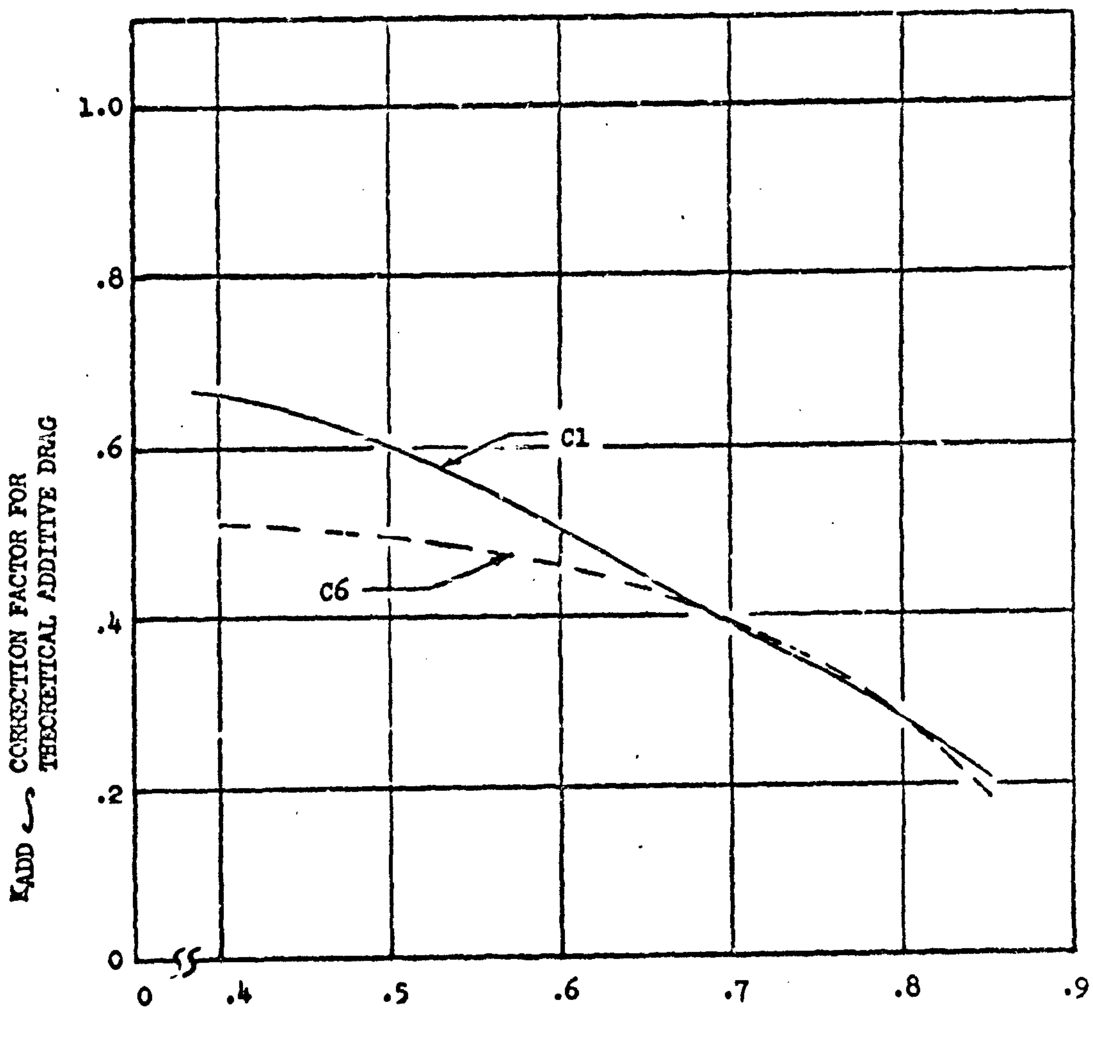


Figure 71. K_{ADD}, R4SP4C1, C6, M_o = 0.865

CONFIG.	ι°	β°	M_0	(A_0/A_c) ref.
R4SP406	5°	•	.865	0.774

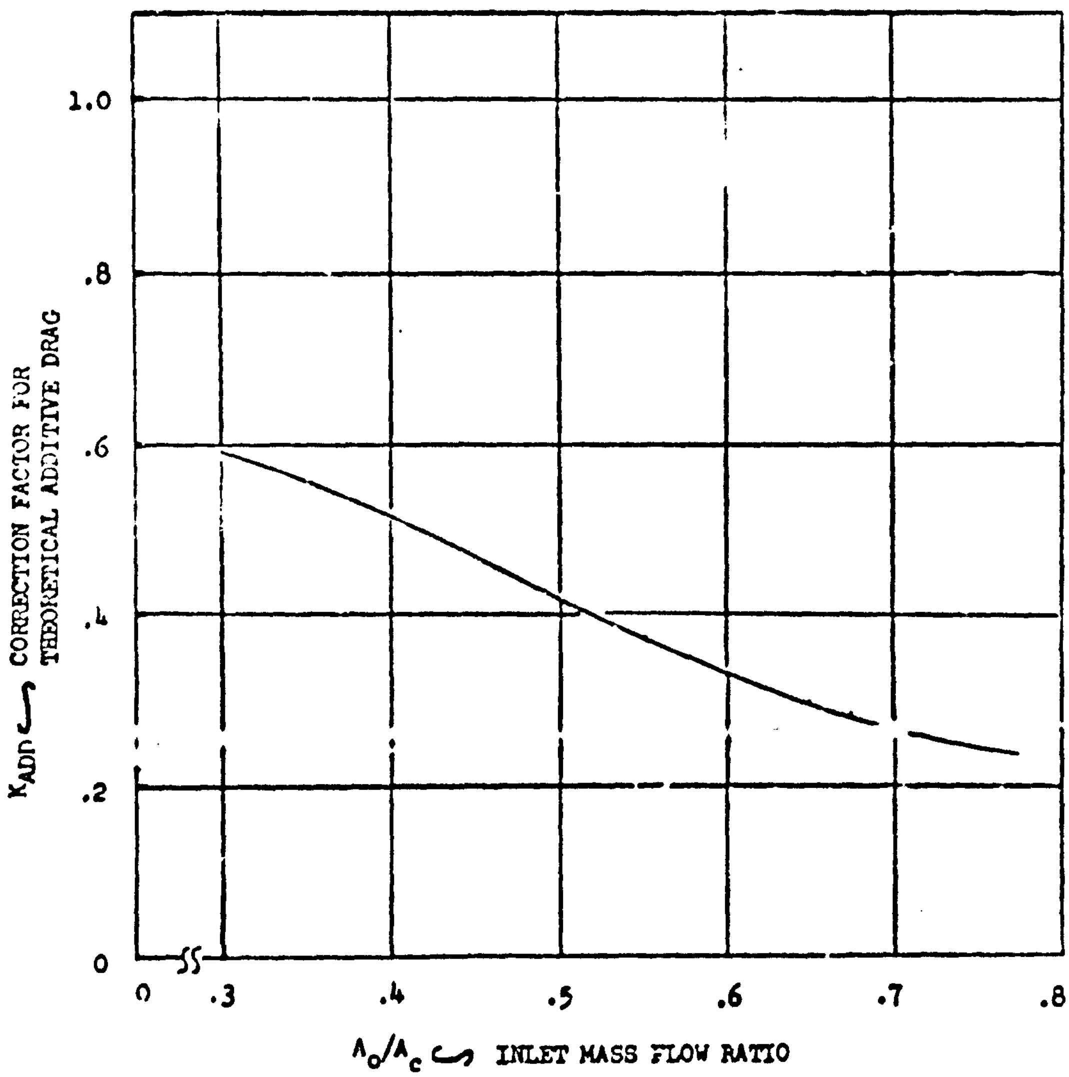


Figure 72. K_{ADD}, R4SP406, M_0 = 0.865

CONFIG.	α°	β°	M_o	$(A_o/A_c)_{ref.}$
R4SP4C1	5°	12°	0.865	0.712
C6	"	"	"	"

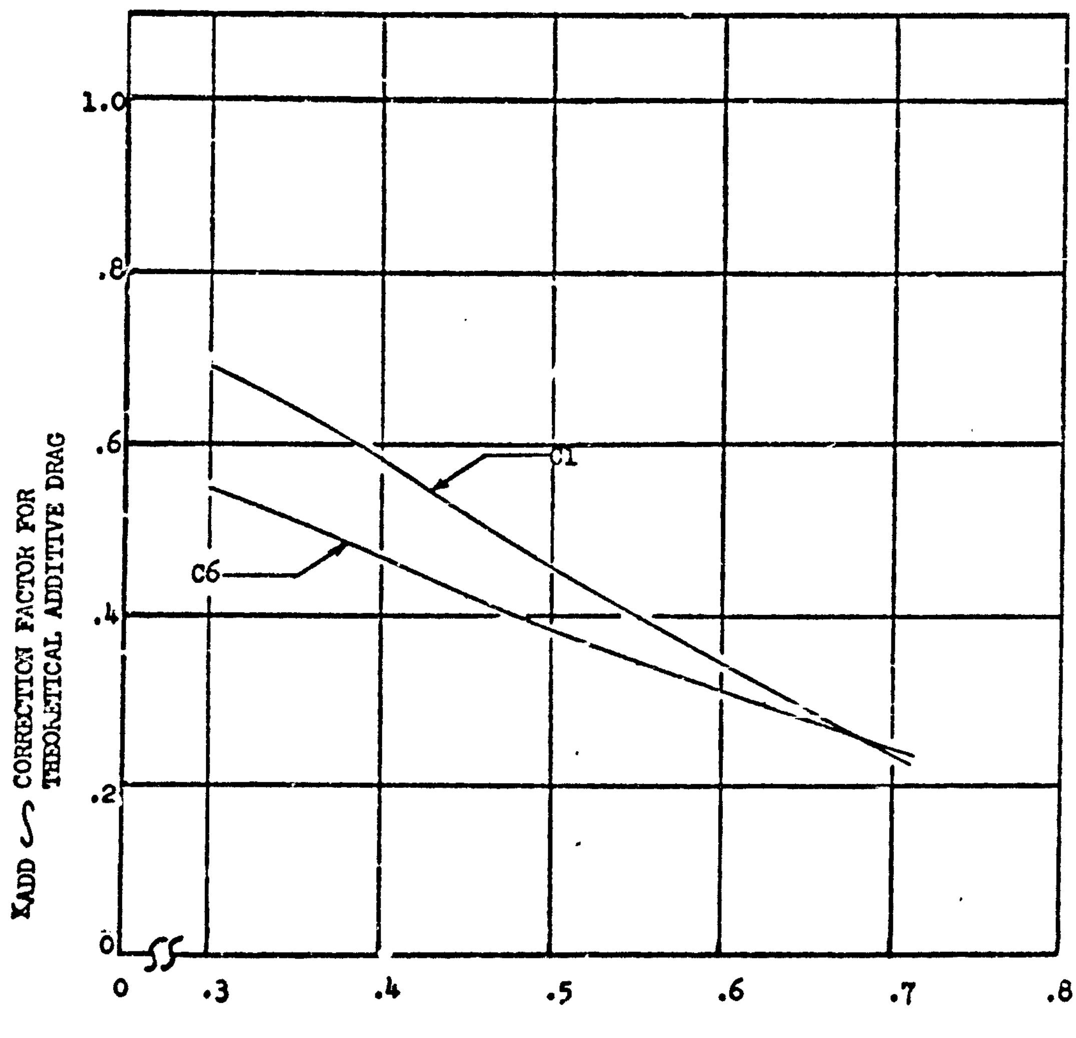


Figure 73. K_{ADD}, R4SP4C1, C6, $M_o = 0.865$

CONFIG.	$\alpha°$	$\beta°$	M_o	$(A_o/A_c)_{ref.}$
R1SP1C1	5°	5°	1.09	0.796
C2	"		"	"
C3	"	"	"	"
C4	"	"	"	"
C5	"	"	"	"
C6	"	"	"	"

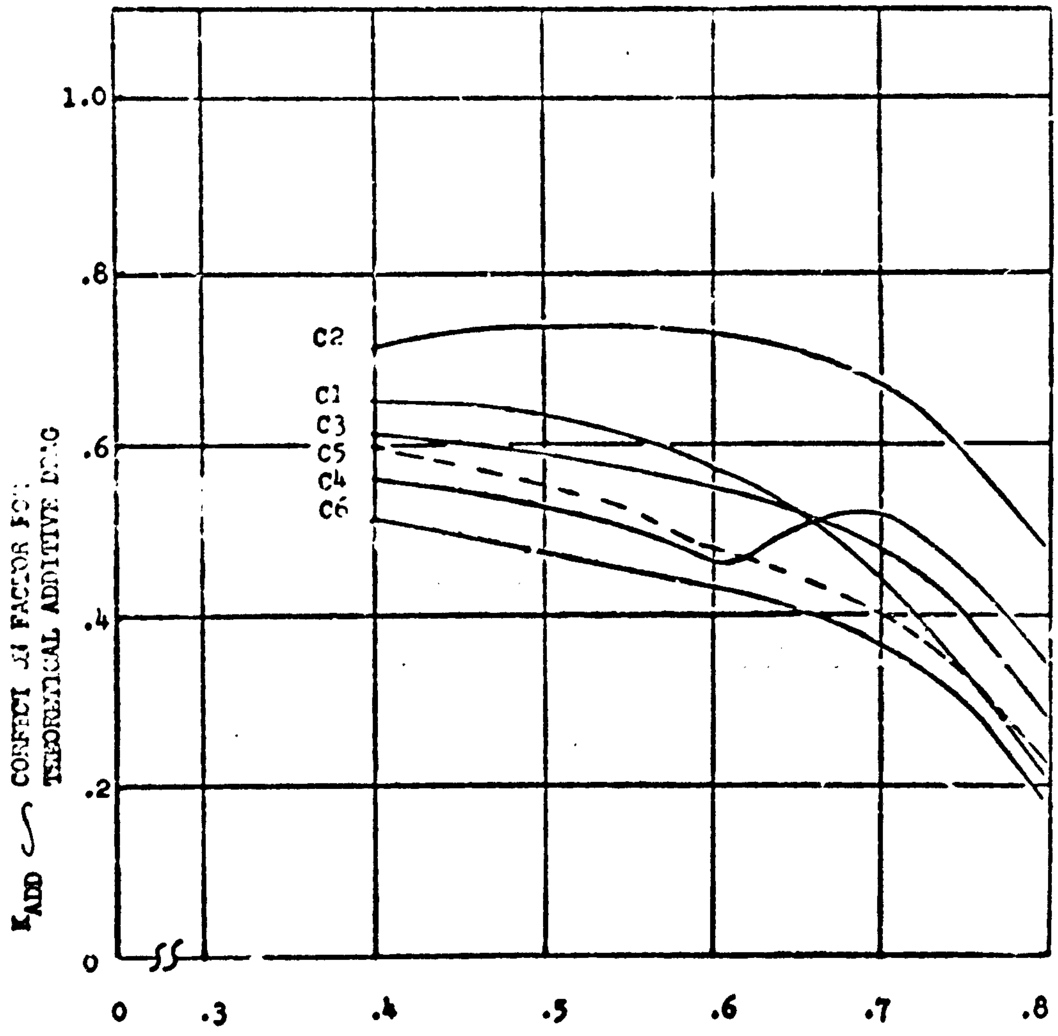


Figure 74. K_{ADD}, R1SP1C1-C6, M_o = 1.09

CONFIG.	$\alpha°$	$\beta°$	M_o	(A_o/A_c) ref.
R1SP1C1	5°	9°	1.09	0.715

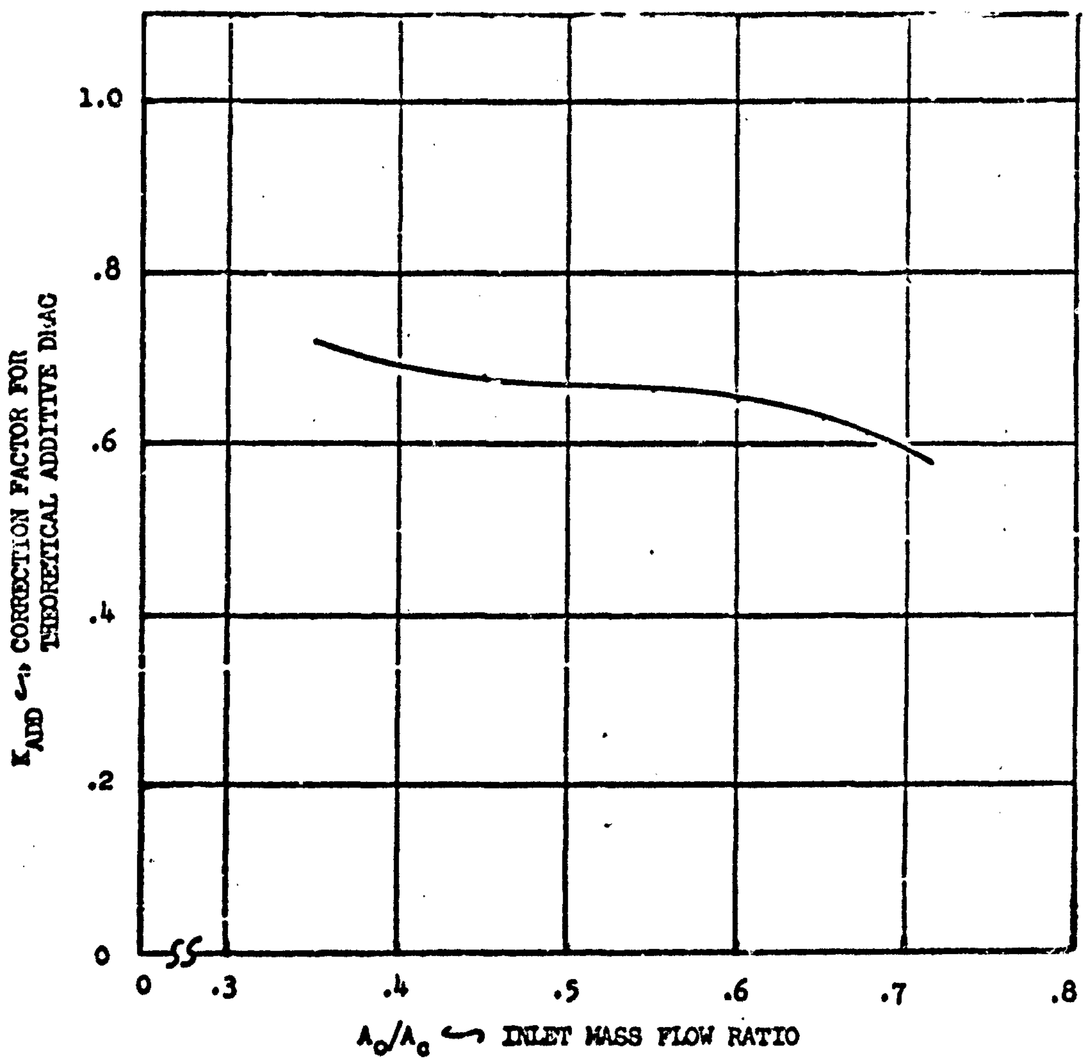


Figure 7f K_{ADD}, R1SP1C1, M_o = 1.09

	$\alpha°$	$\beta°$	M_0	(A_0/A_c) ref.
R1SP1C1	5°	12°	1.09	0.715

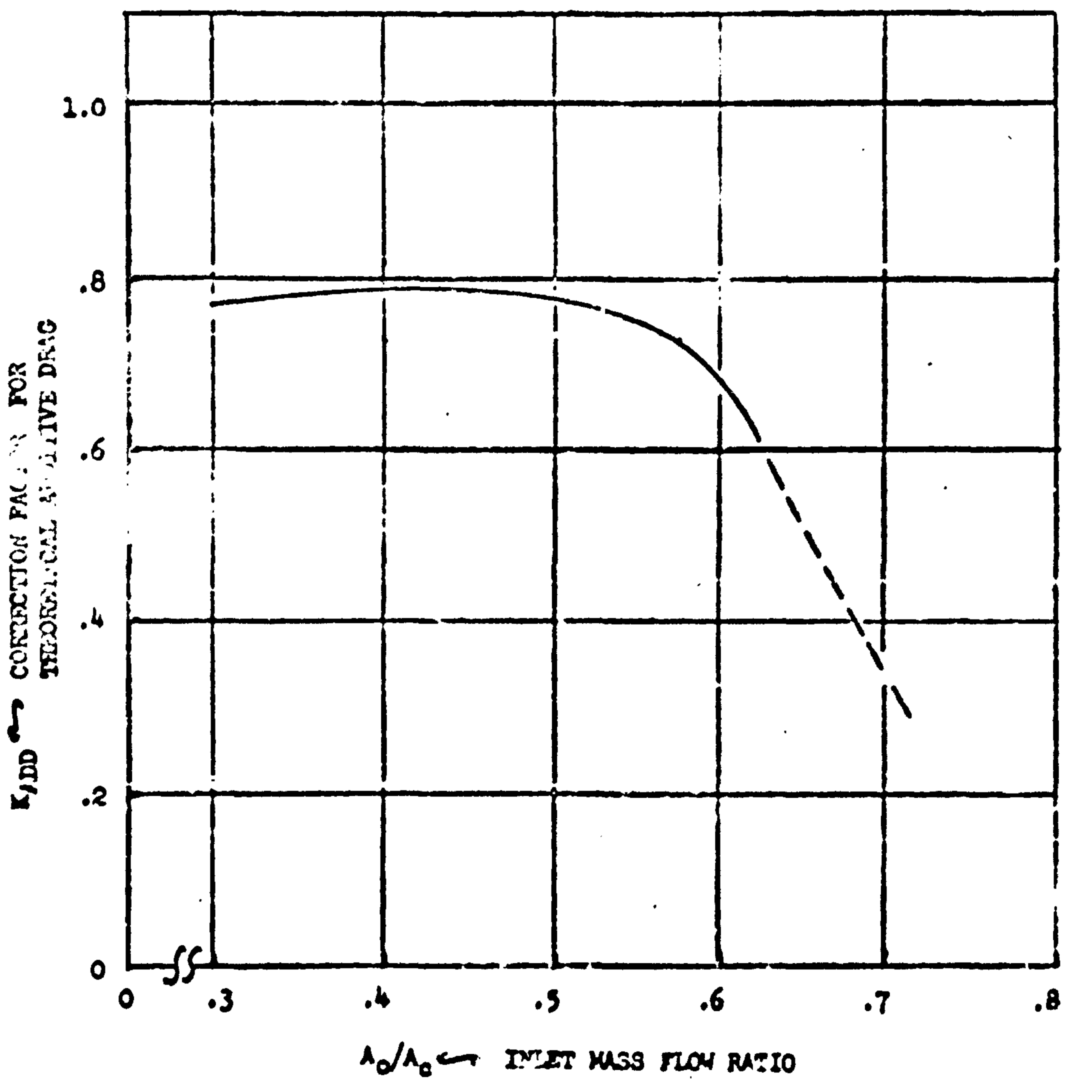


Figure 76. K_{ADD}, R1SP1C1, M_0 = 1.09

CONFIG.	$\alpha°$	$\beta°$	M_0	(A_0/A_c) ref.
R1SP2C1	5°	5°	1.09	0.796

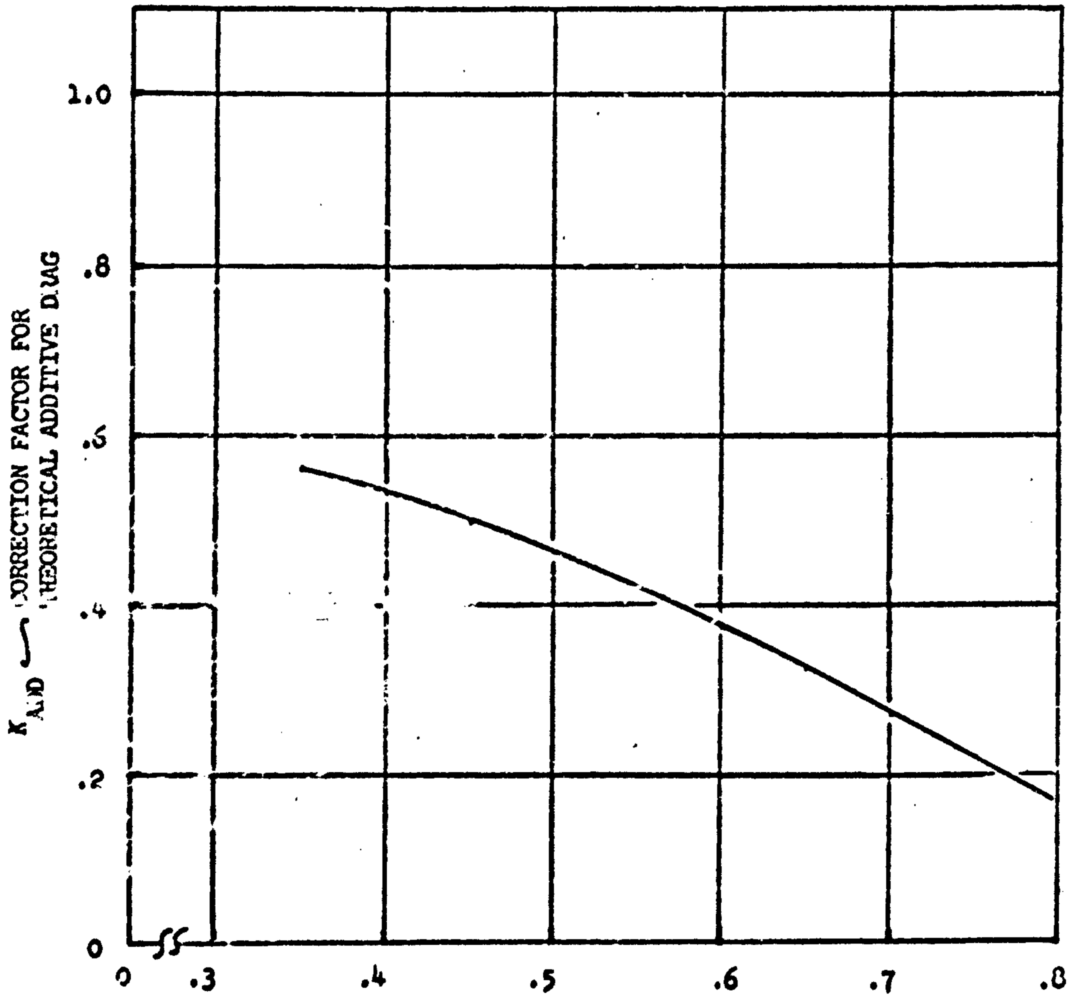


Figure 77. K_{ADD}, R1SP2C1, M_0 = 1.09

CONFIG.	$\gamma°$	$\beta°$	M_o	(A_c/A_c) ref.
R1SP3C1	5°	[illegible]	1.11	0.796

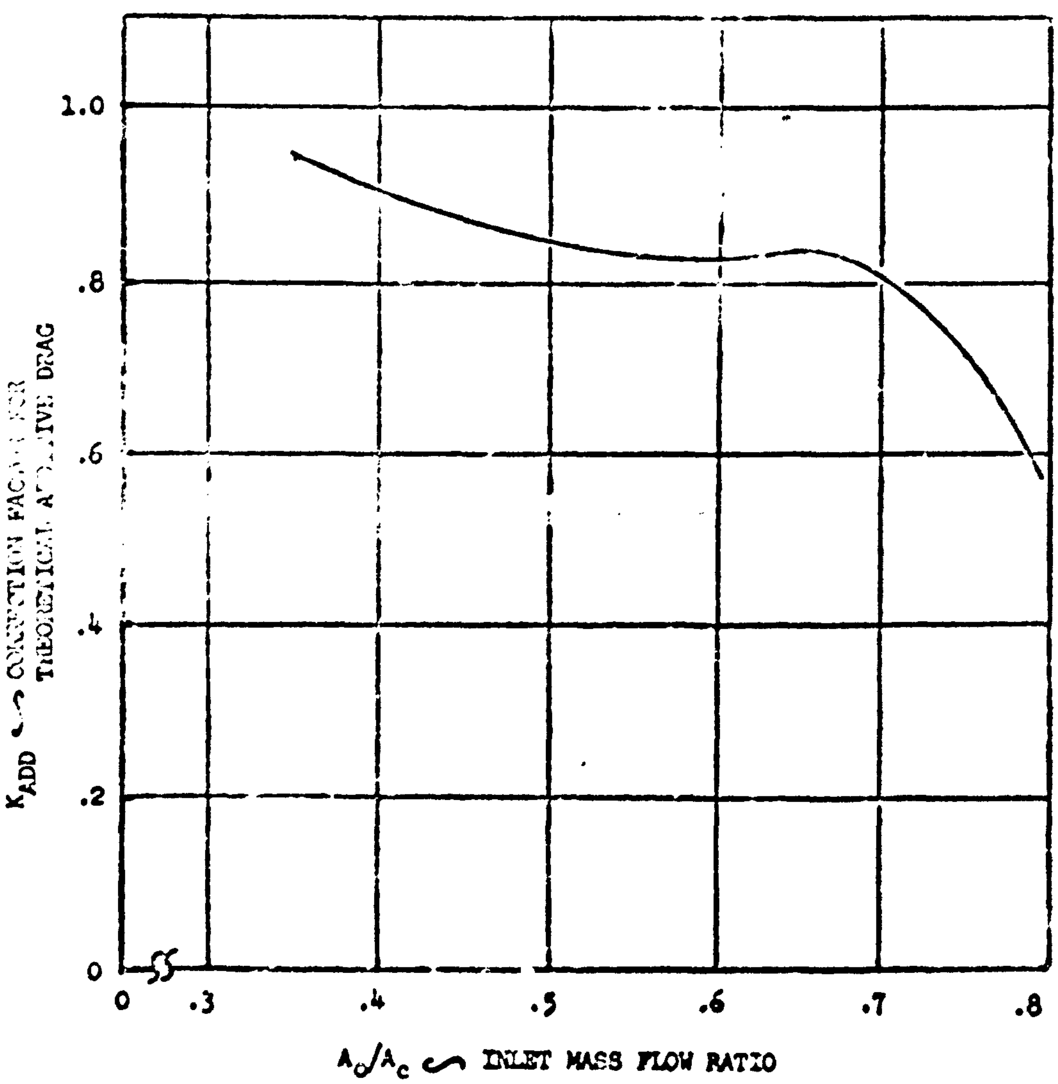


Figure 78. K_{ADD}, R1SP3C1, M_o = 1.11

CONFIG.	$\alpha°$	$\beta°$	M_o	(A_o/A_c) ref.
R3SP1C1	12°	12°	1.11	0.50

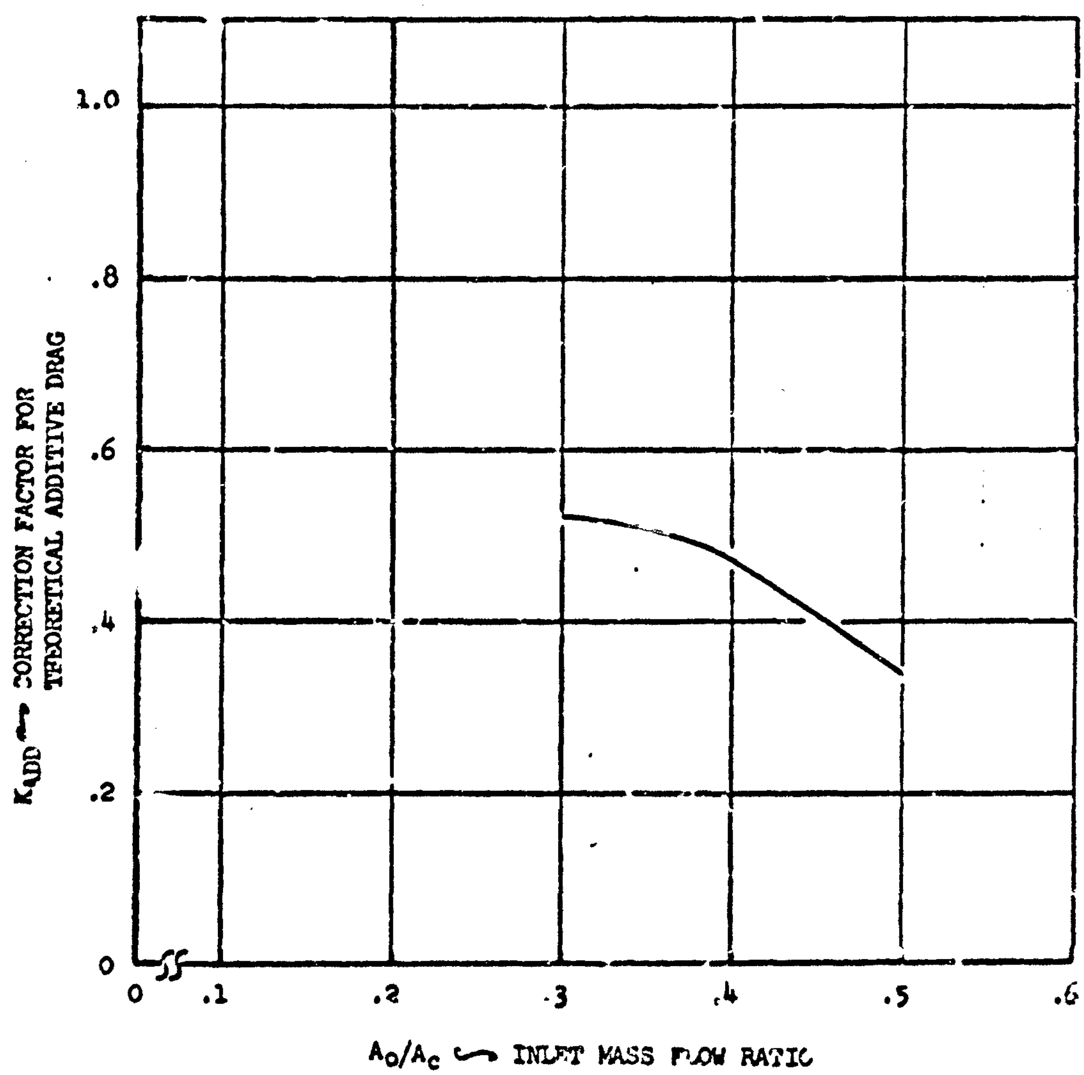


Figure 79. K_{ADD}, R3SP1C1, M_o = 1.11

CONFIG.	$\alpha°$	$\beta°$	M_0	(A_0/A_c)ref.
R4SP4C1	5°	0°	1.11	0.8[illegible]
C4	"	"	"	"
C6	"	"	"	"

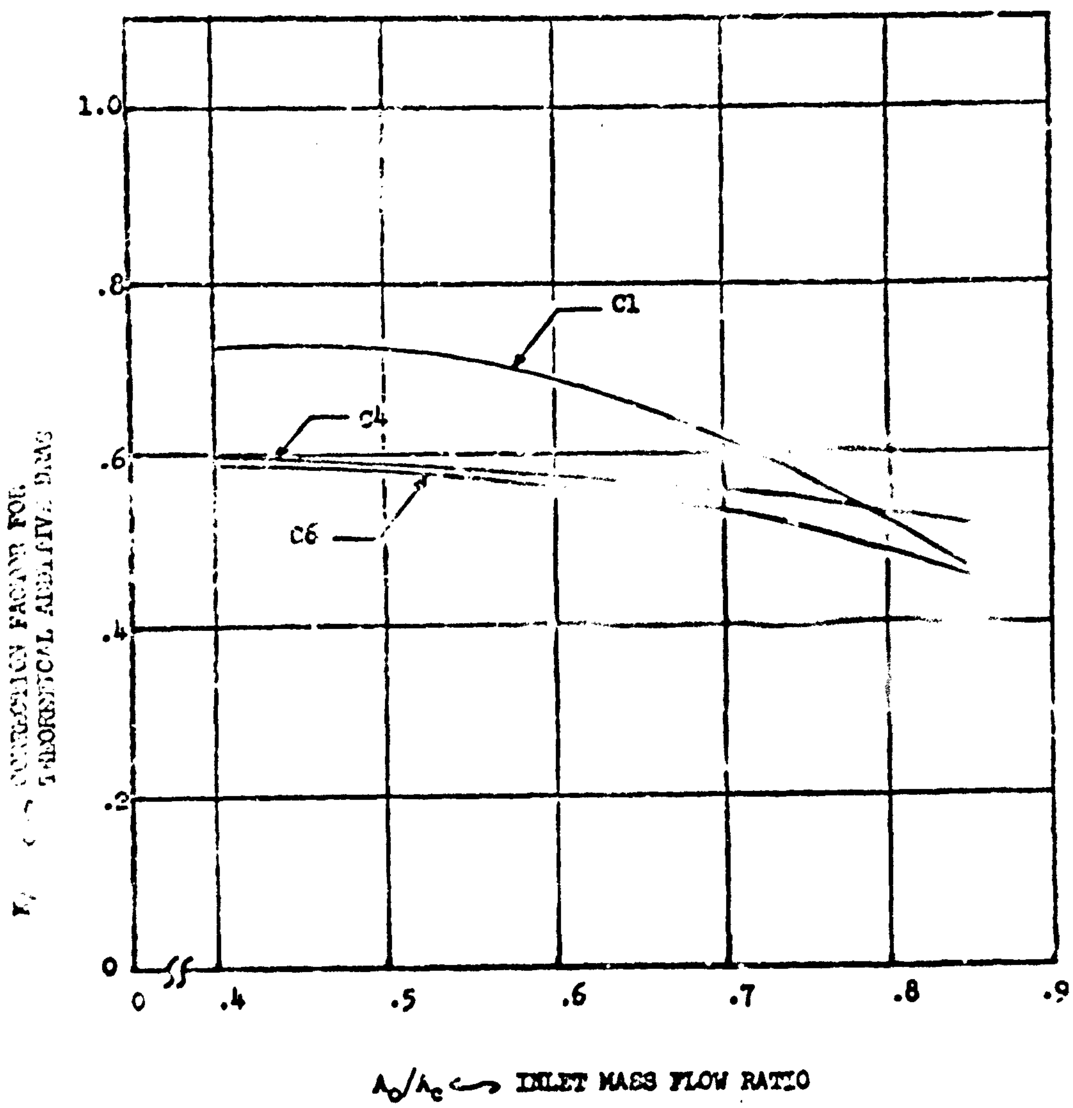


Figure 80. KADD, R4SP4C1, C4, C6, M_0 = 1.11

CONFIG.	$\alpha°$	$\beta°$	M_o	(A_o/A_c) ref.
R4SP4C6	5°	9°	1.11	.774

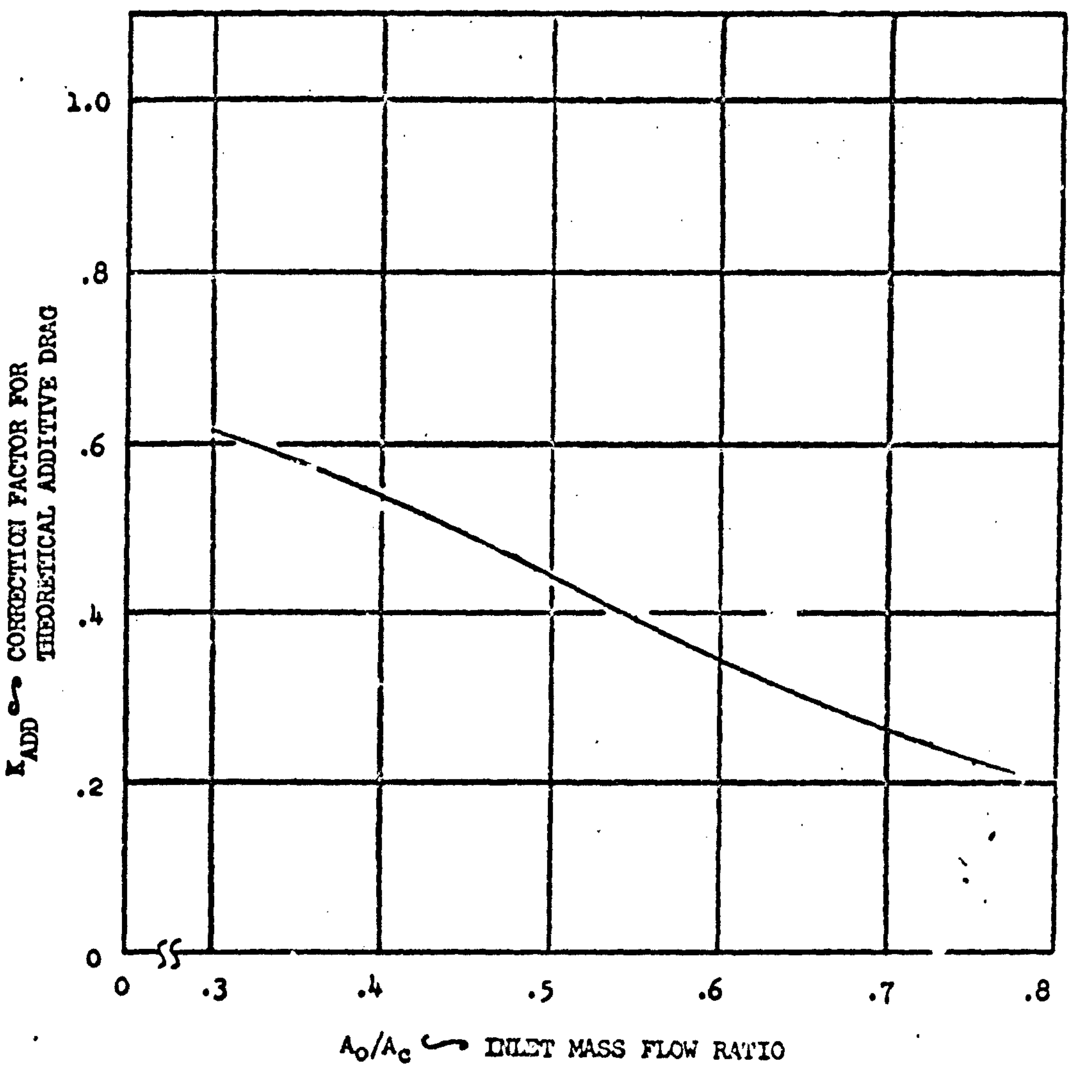
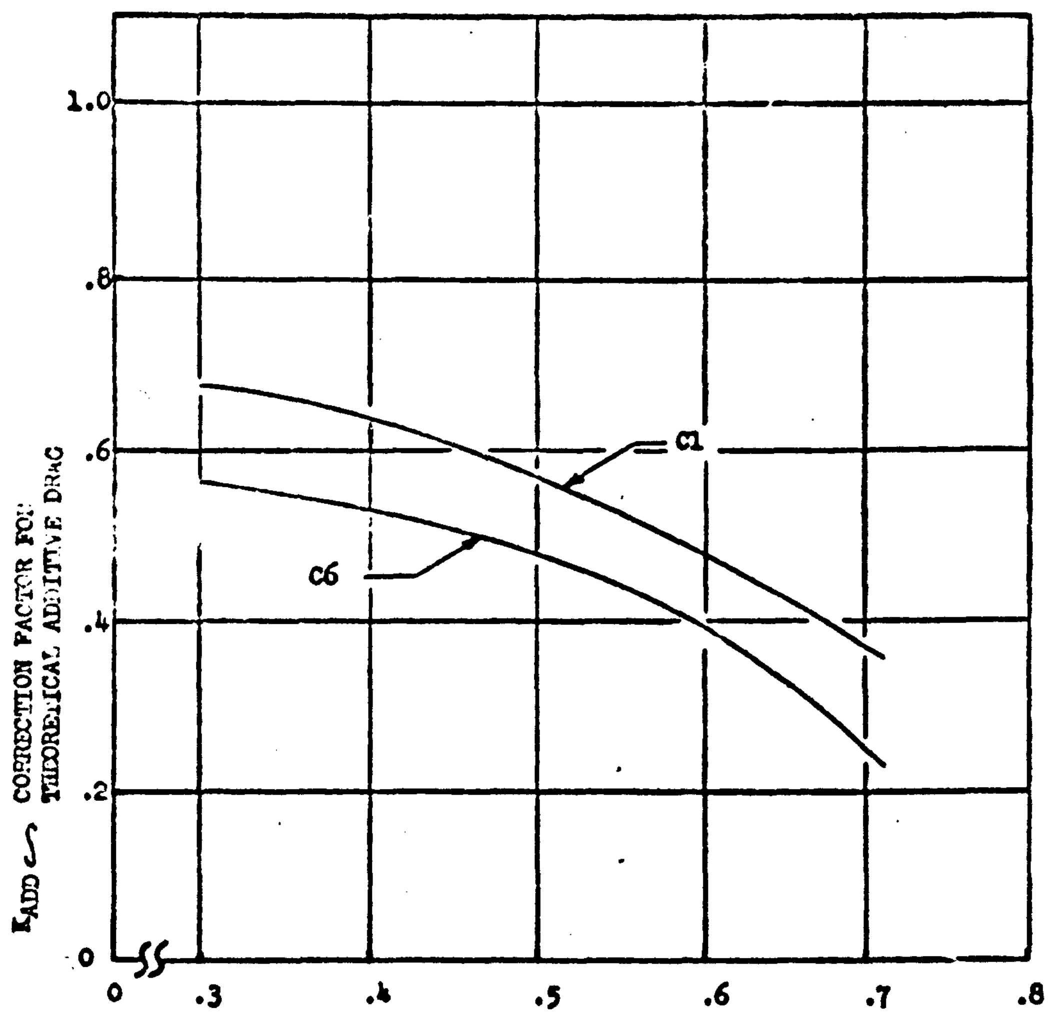


Figure 81. K_{ADD}, R4SP4C6, M_o = 1.11

CONFIG.	$\alpha°$	$\beta°$	M_o	$(A_o/A_c)_{ref.}$
R4SP4C1	[illegible]	12°	1.11	0.712
C6	"	"	"	"



A_o/A_c ~ INLET MASS FLOW RATIO

Figure 82. K_{ADL}, R4SP4C1, C4, M_o = 1.11

CONFIG.	$\varphi°$	$\beta°$	Mo	$(A_o/A_c)_{ref.}$
R1SP1C1	5°	5°	1.29	0.780
C2	"	"	"	"
C3	"	"	"	"
C4	"	"	"	"
C5	"	"	"	"
C6	"	"	"	"

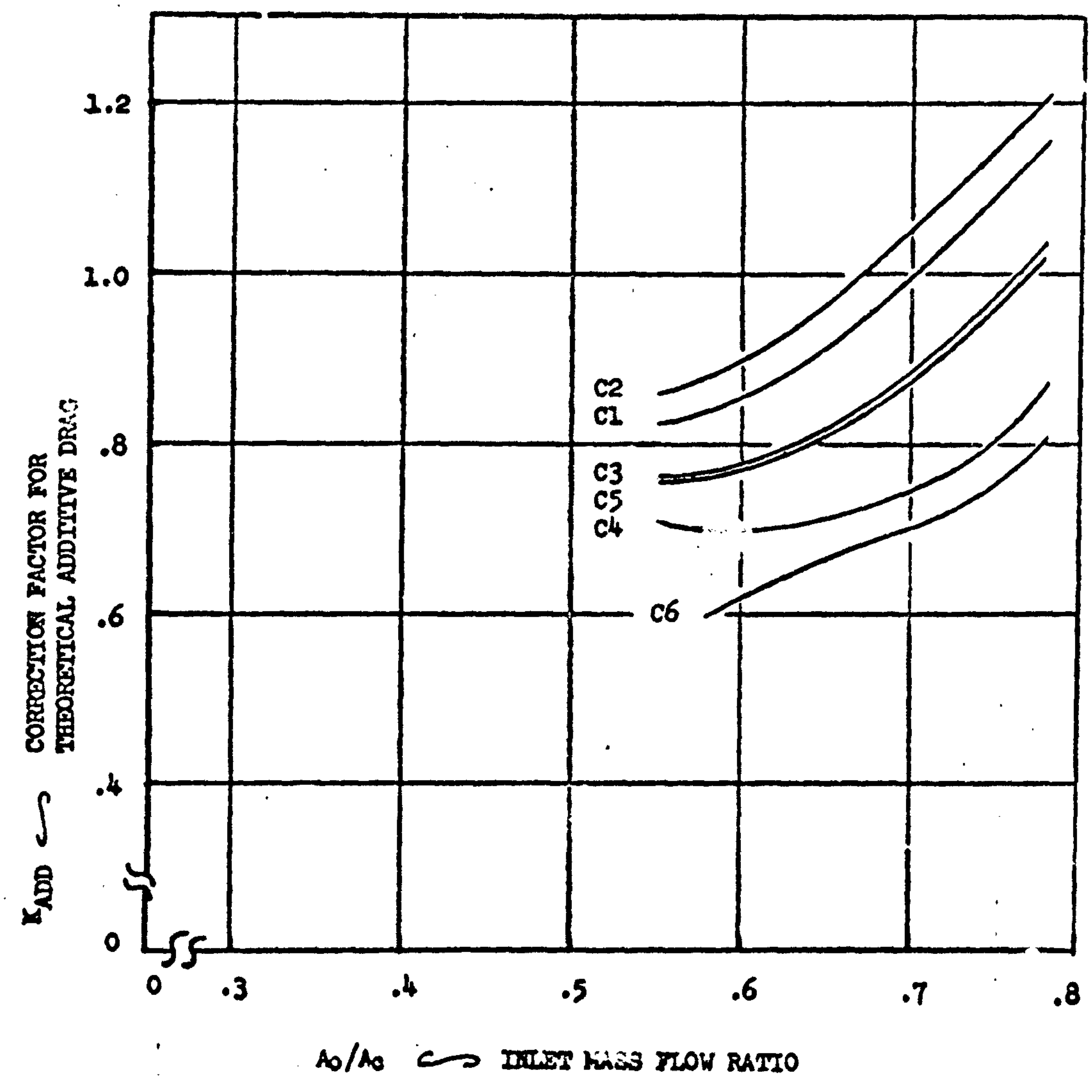


Figure 83. K_{ADD}, R1SP1C1-C6, M_o = 1.29

CONFIG.	$\alpha°$	$\beta°$	M_0	(A_0/A_c) ref.
R1SP2C1	5°	5°	1.29	0.75

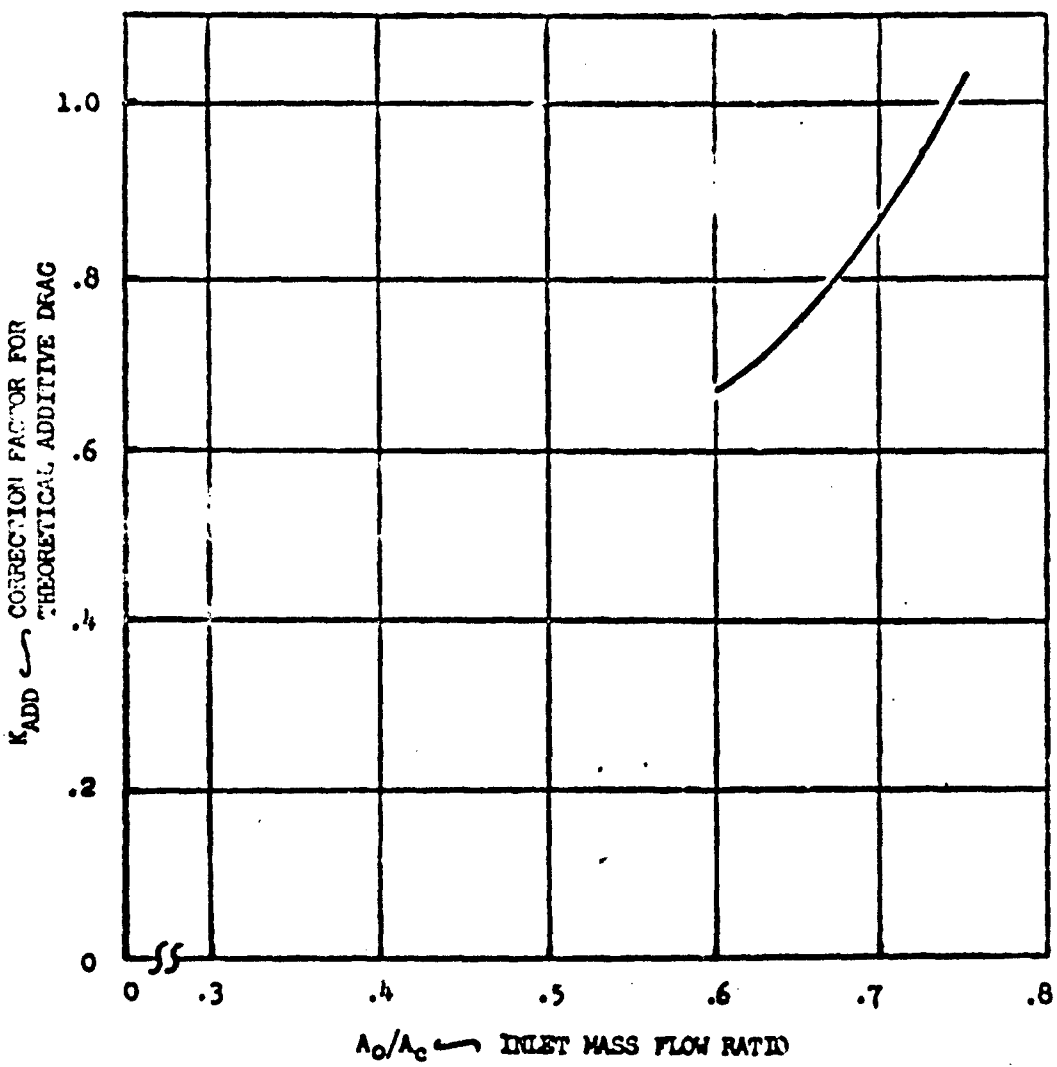


Figure 84. K_{ADD}, R1SP2C1, M_0 = 1.29

CONFIG.	$\alpha°$	$\beta°$	M_o	(A_o/A_c) ref.
R1SP3C1	5°	5°	1.31	0.842

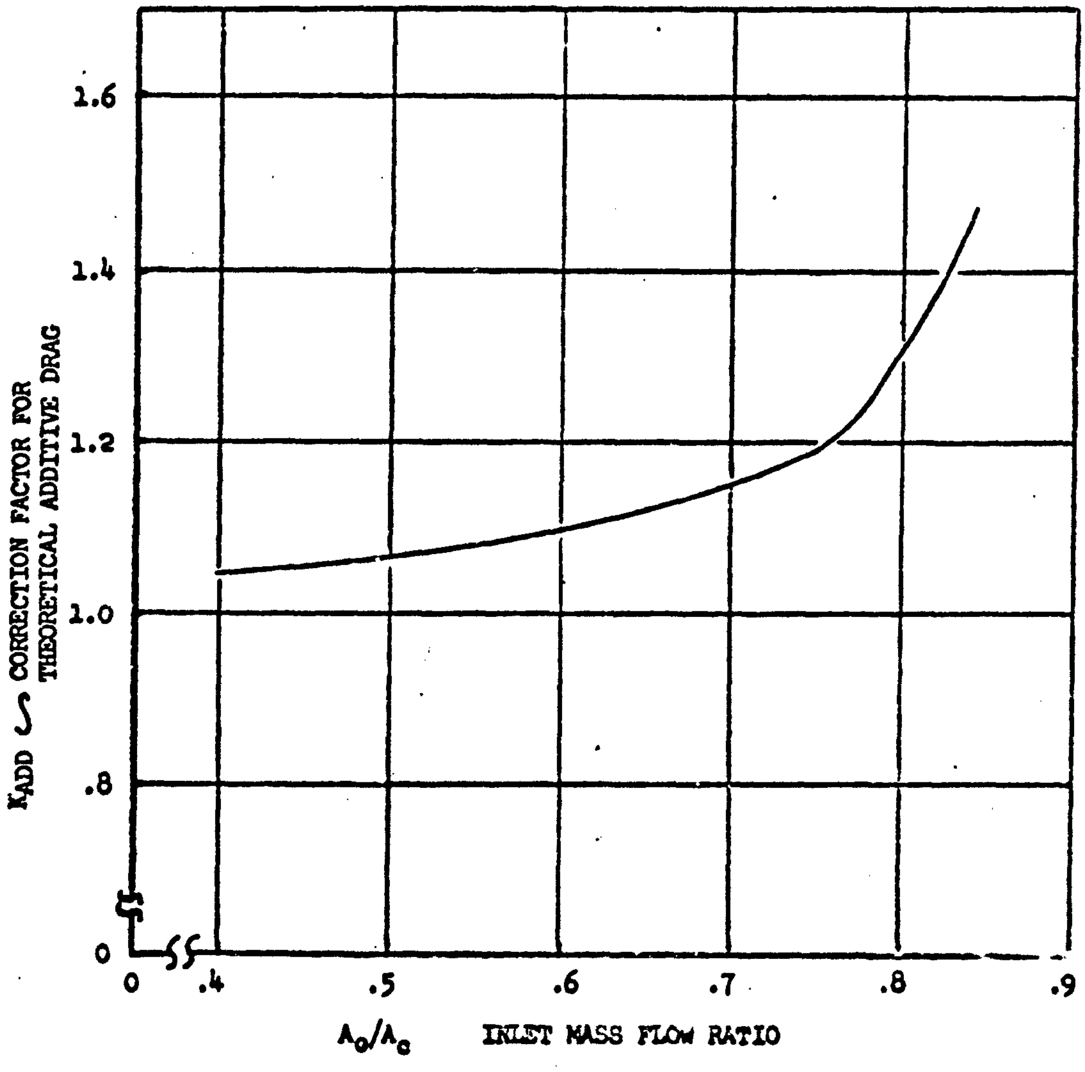


Figure 85. K_{ADD}, R1SP3C1, M_o = 1.31

CONFIG.	$\alpha°$	$\beta°$	M_0	(A_0/A_c) ref.
R2SP1C1	7°	7°	1.31	0.752

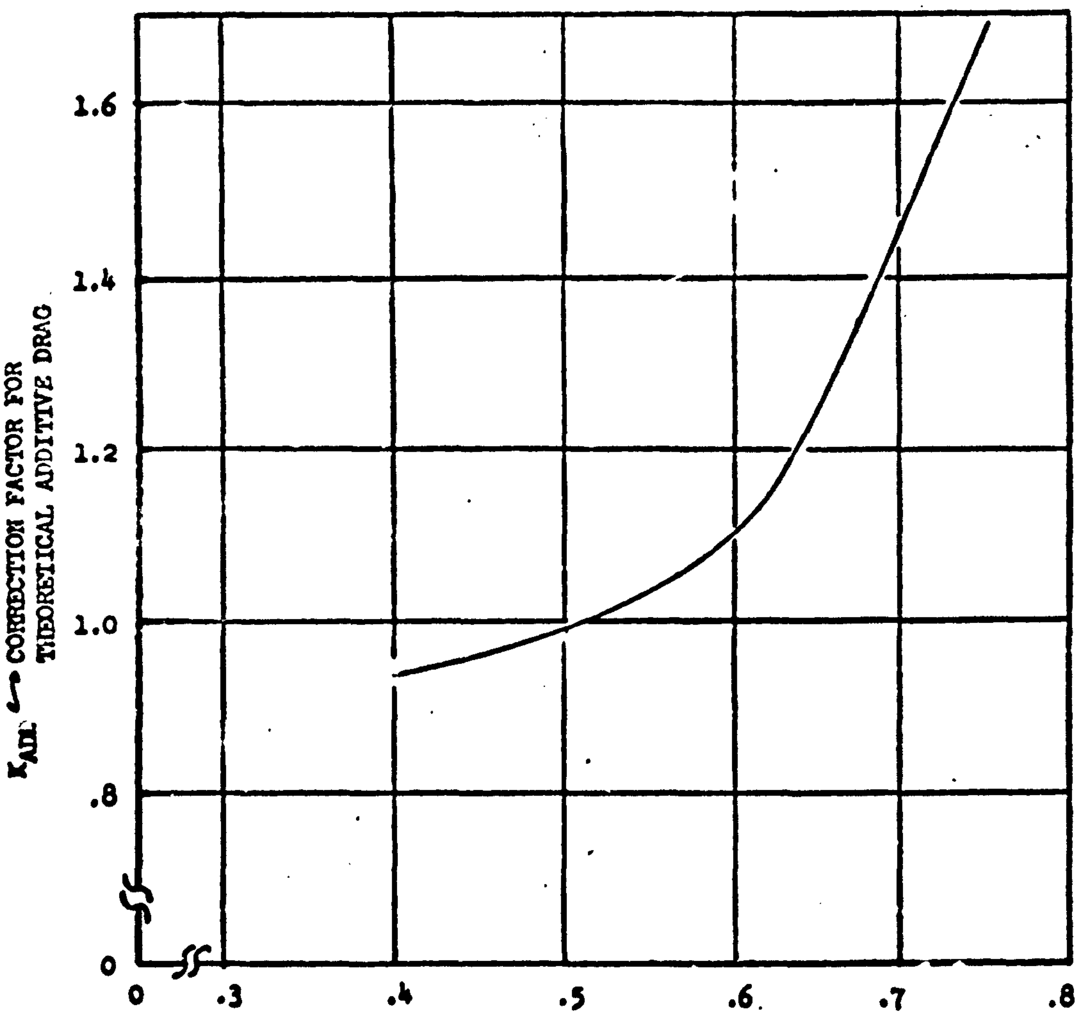


Figure 86. K_{ADD}, R2SP1C1, M_0 = 1.31

CONFIG.	$\alpha°$	β	Mo	(A_o/A_c) ref.
R3SP1C1	12°	12°	1.31	0.50

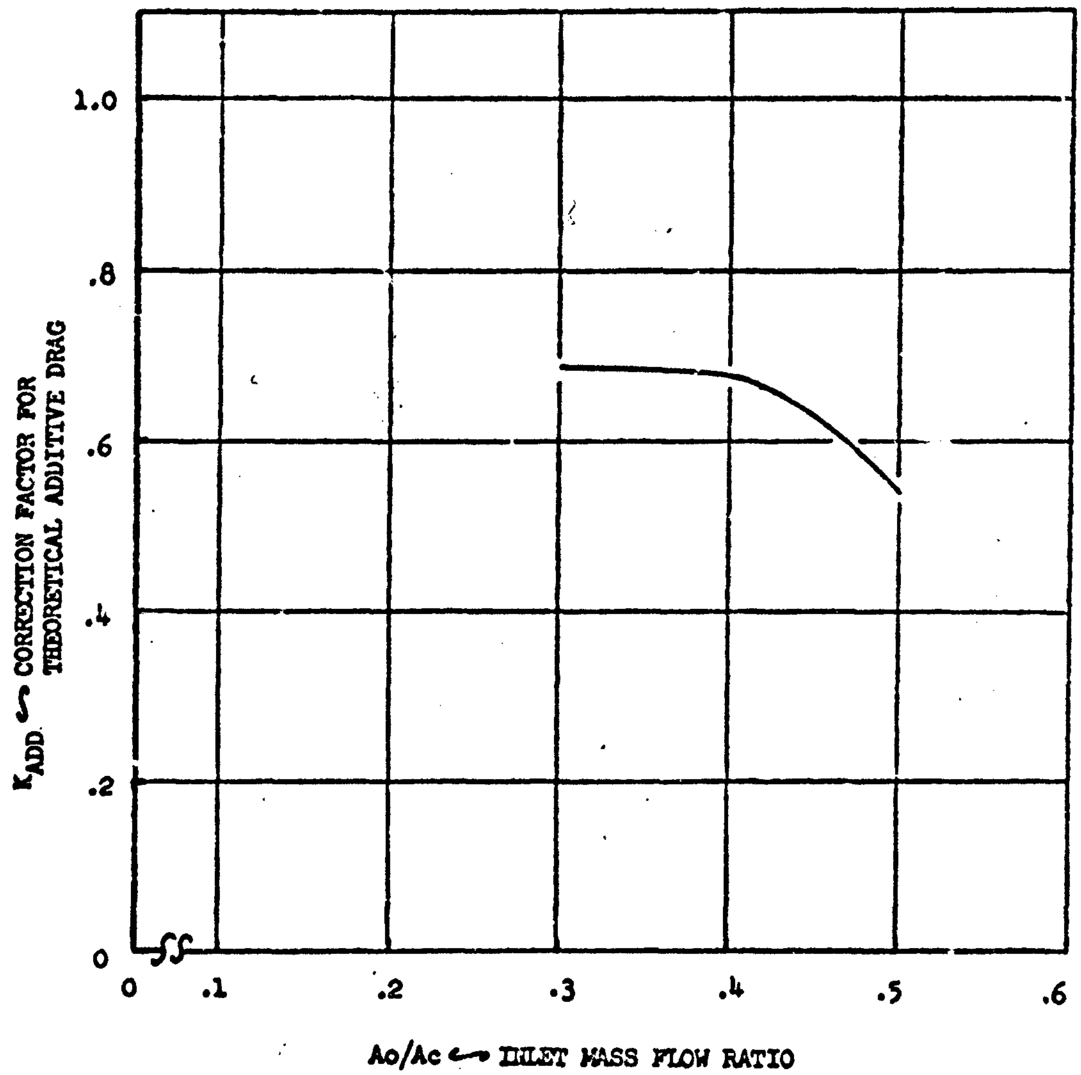


Figure 87. K_{ADD}, R3SP1C1, Mo = 1.31

CONFIG.	α°	β°	M_o	$(A_o/A_c)_{ref.}$
R4SP4C1	5°	5°	1.31	0.864
C4	"	"	"	"
C6	"	"	"	"

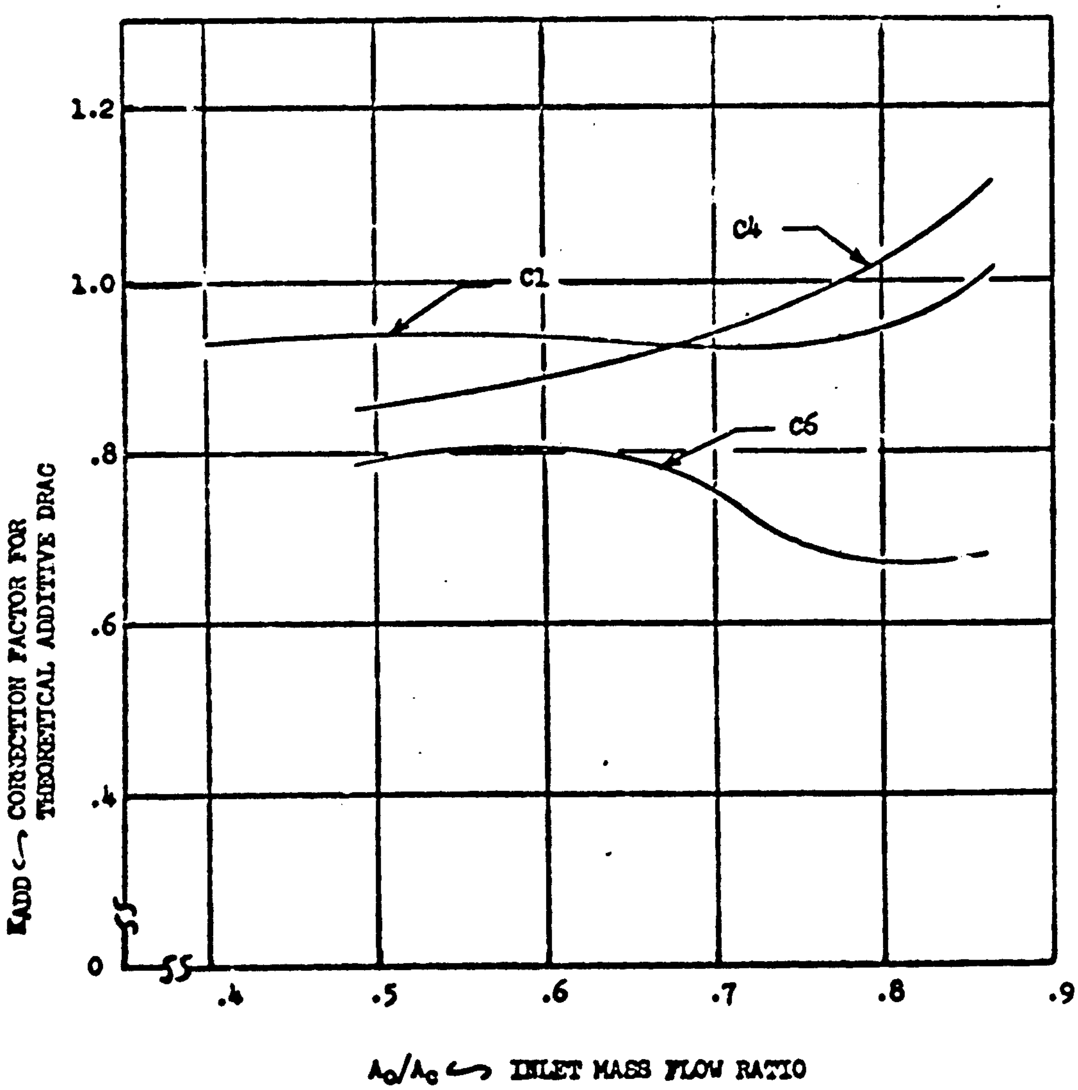


Figure 88. K_{ADD}, R4SP4C1, C4, C6, M_o = 1.31

CONFIG.	$\alpha°$	$\beta°$	M_o	$(A_o/A_c)_{ref.}$
R1SP1C1	5	5	1.39	0.799
C2	"	"	"	"
C3	"	"	"	"
C4	"	"	"	"
C5	"	"	"	"
C6	"	"	"	"

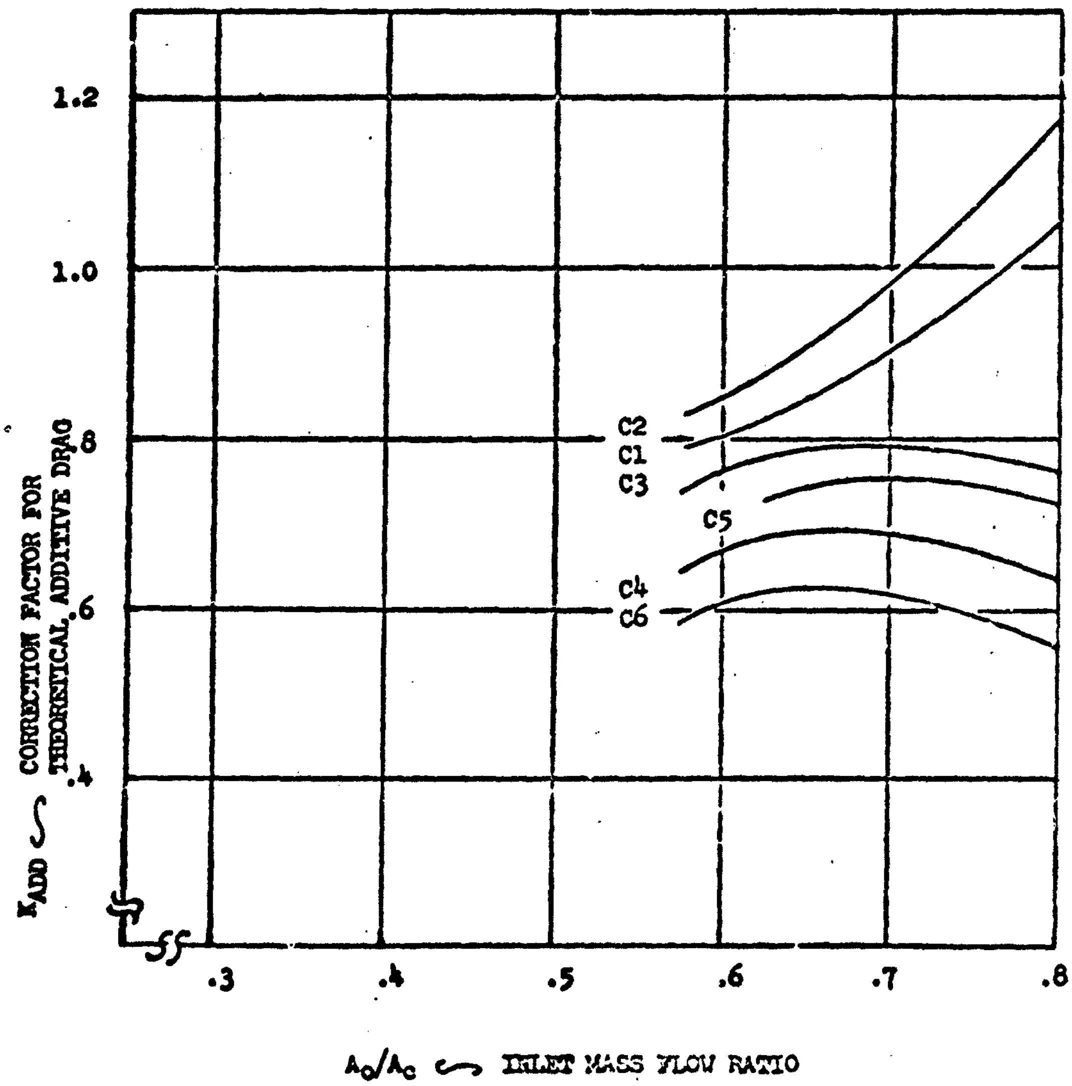


Figure 89. K_{ADD}, R1SP1C1-C6, M_o = 1.39

CONFIG.	$\alpha°$	$\beta°$	M_0	(A_0/A_c) ref.
R1SP2C1	5°	5°	1.39	0.7675

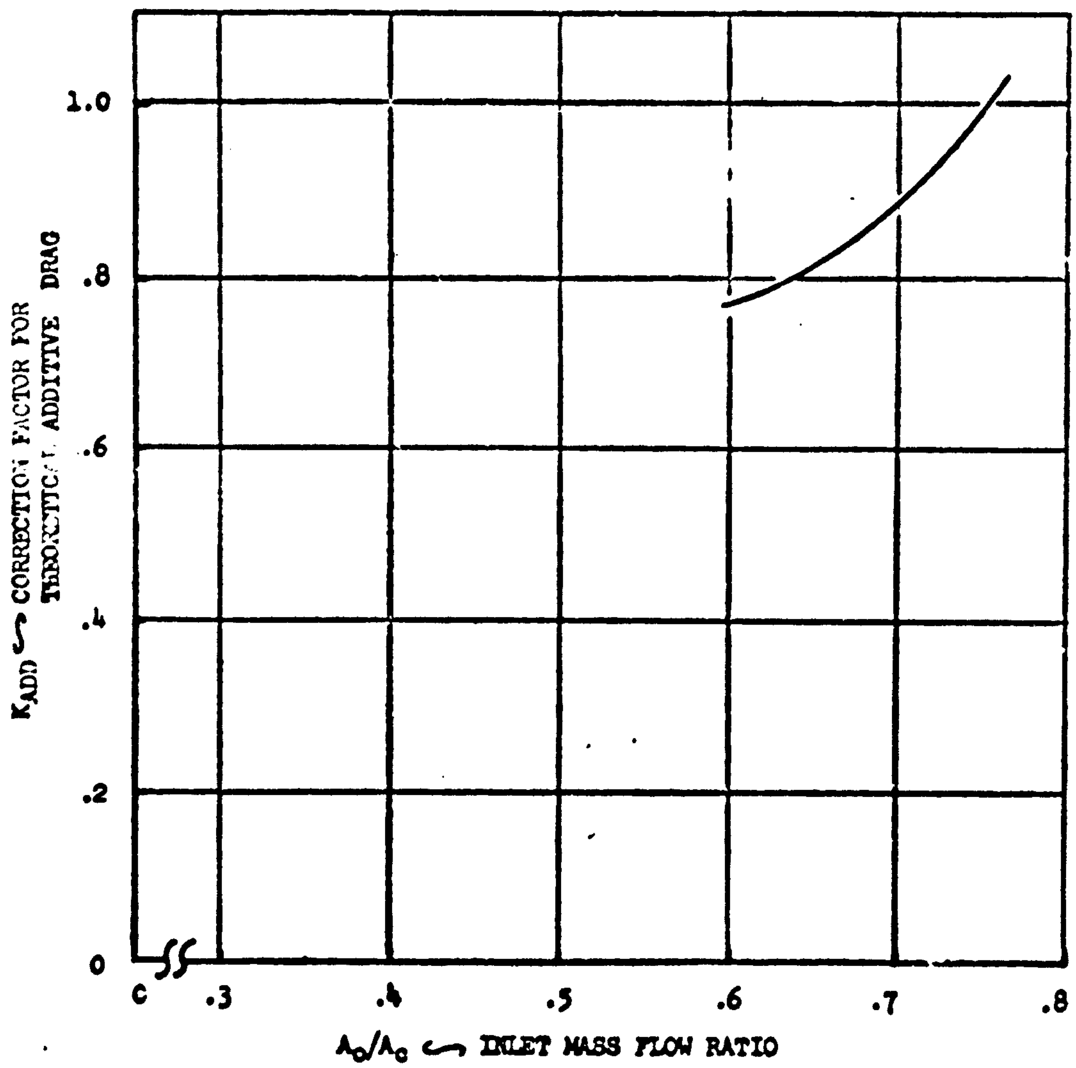


Figure 90. K_{ADD}, R1SP2C1, $M_0 = 1.39$

CONFIG.	$\alpha°$	$\beta°$	M_o	(A_o/A_c) ref.
R1SP3C1	5°	5°	1.41	0.856

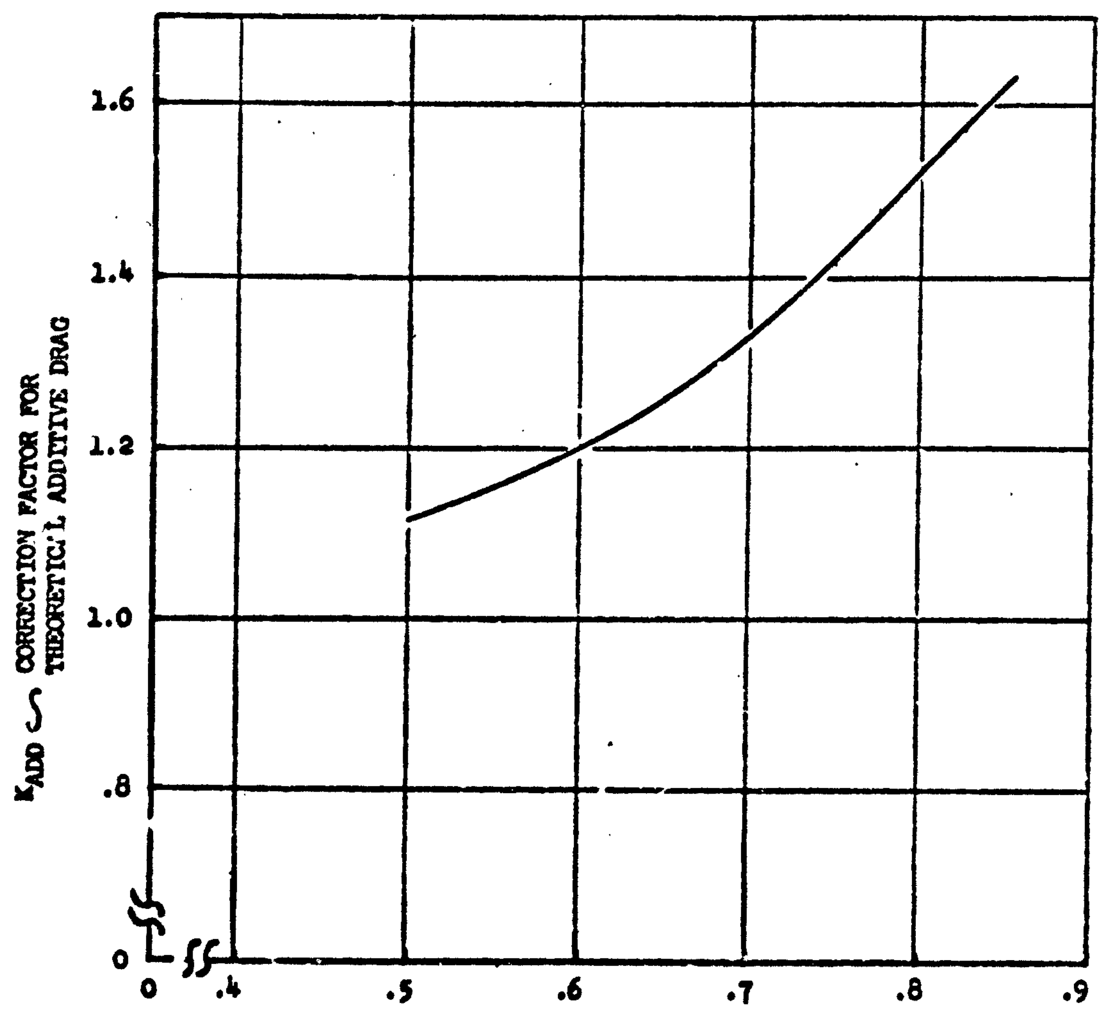


Figure 91. K_{ADD}, R1SP3C1, M_o=1.41

CONFIG.	$\alpha°$	$\beta°$	Mo	(A_o/A_c) ref.
R3SP1C1	12°	12°	1.41	0.50

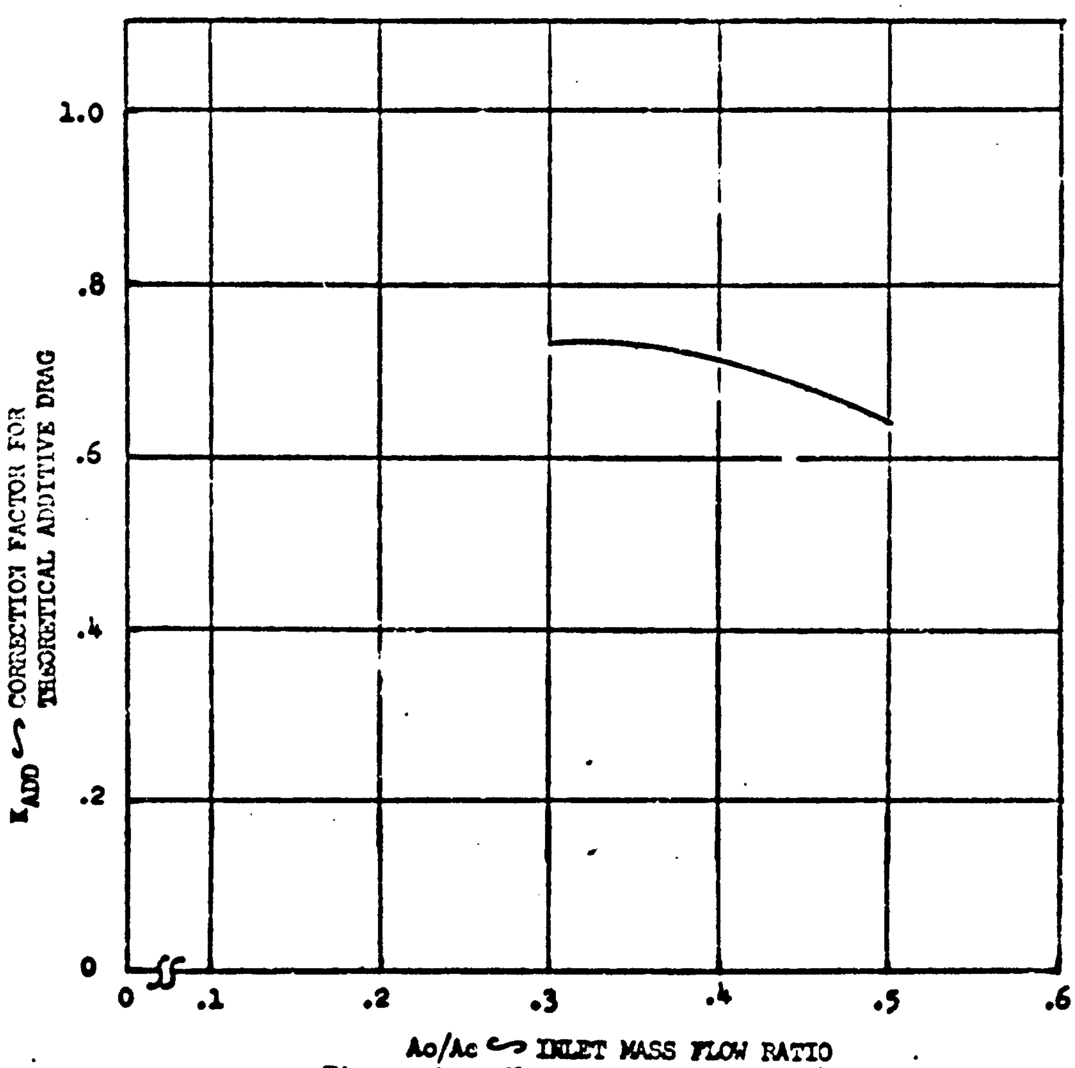


Figure 92. K_{ADD}, R3SP1C1, Mo = 1.41

CONFIG.	α°	β°	M_o	$(A_o/A_c)_{ref.}$
R4SP4C1	5°	5°	1.41	0.885
C4	"	"	"	"
C6	"	"	"	"

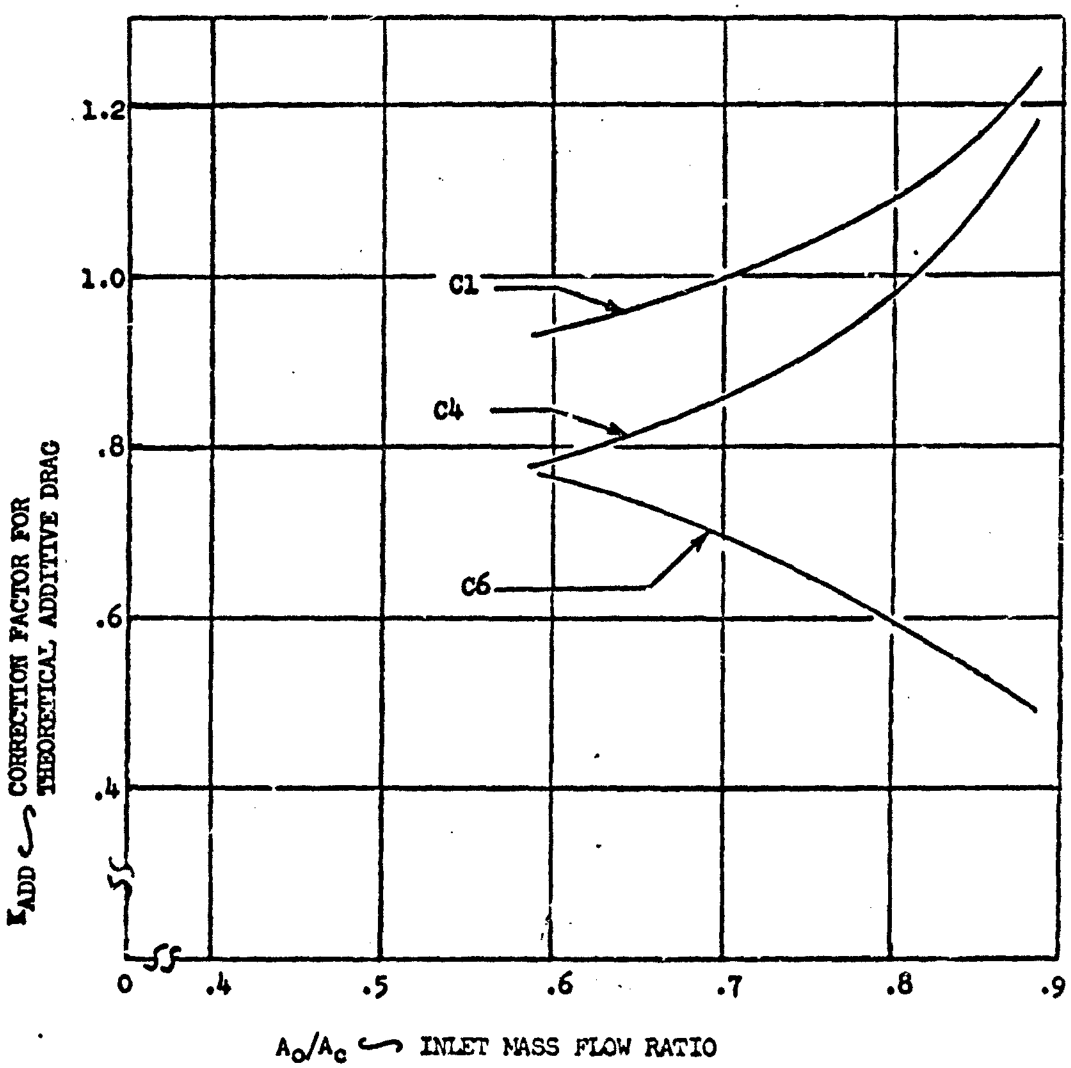


Figure 93. K_{ADD}, R4SP4C1, C4, C6, M_o = 1.41

CONFIG.	$\alpha°$	$\beta°$	M_0	(A_0/A_c) ref.
R1SP1C1	5°	5°	1.69	0.841
C5	"	"	"	"

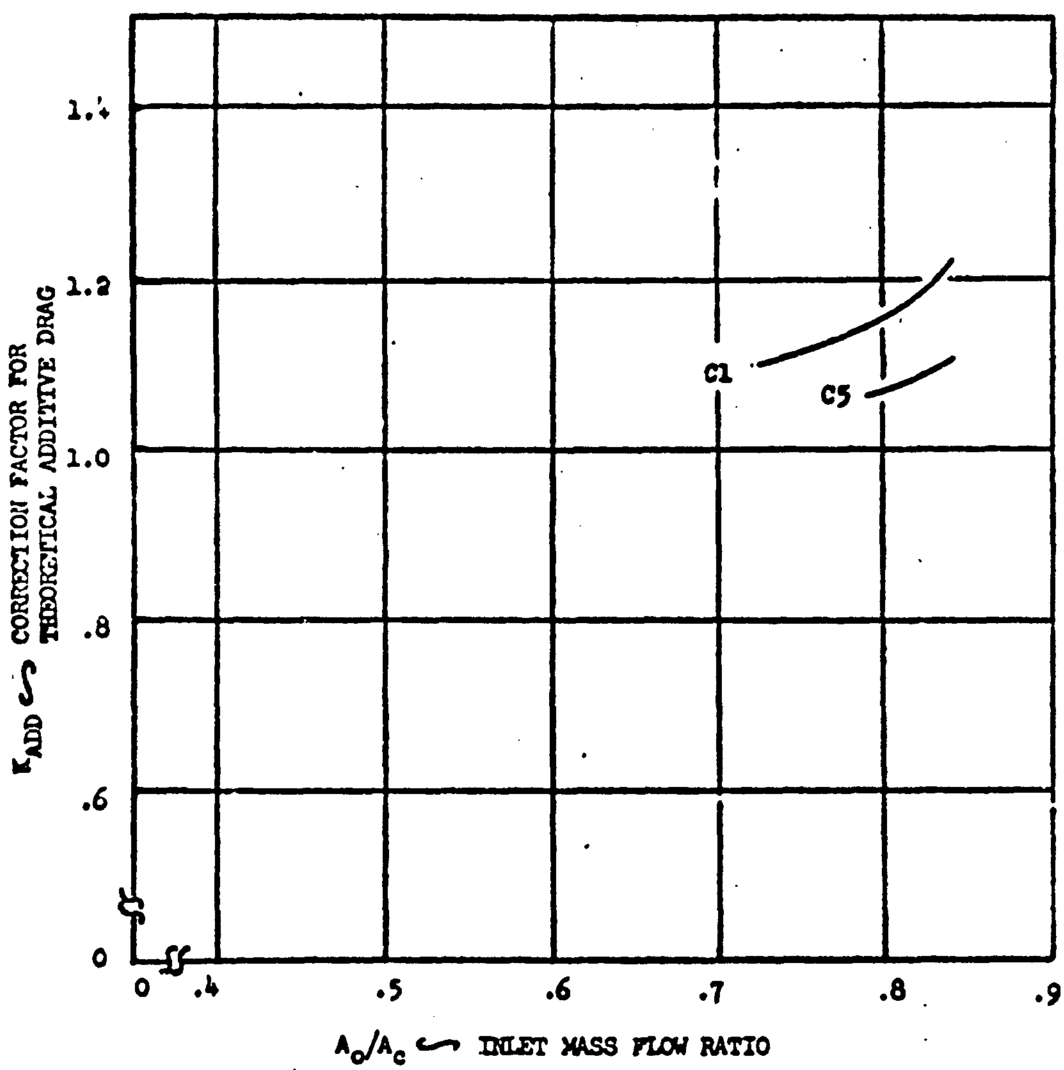


Figure 94. K_{ADD}, R1SP1C1, C5, M_0 = 1.69

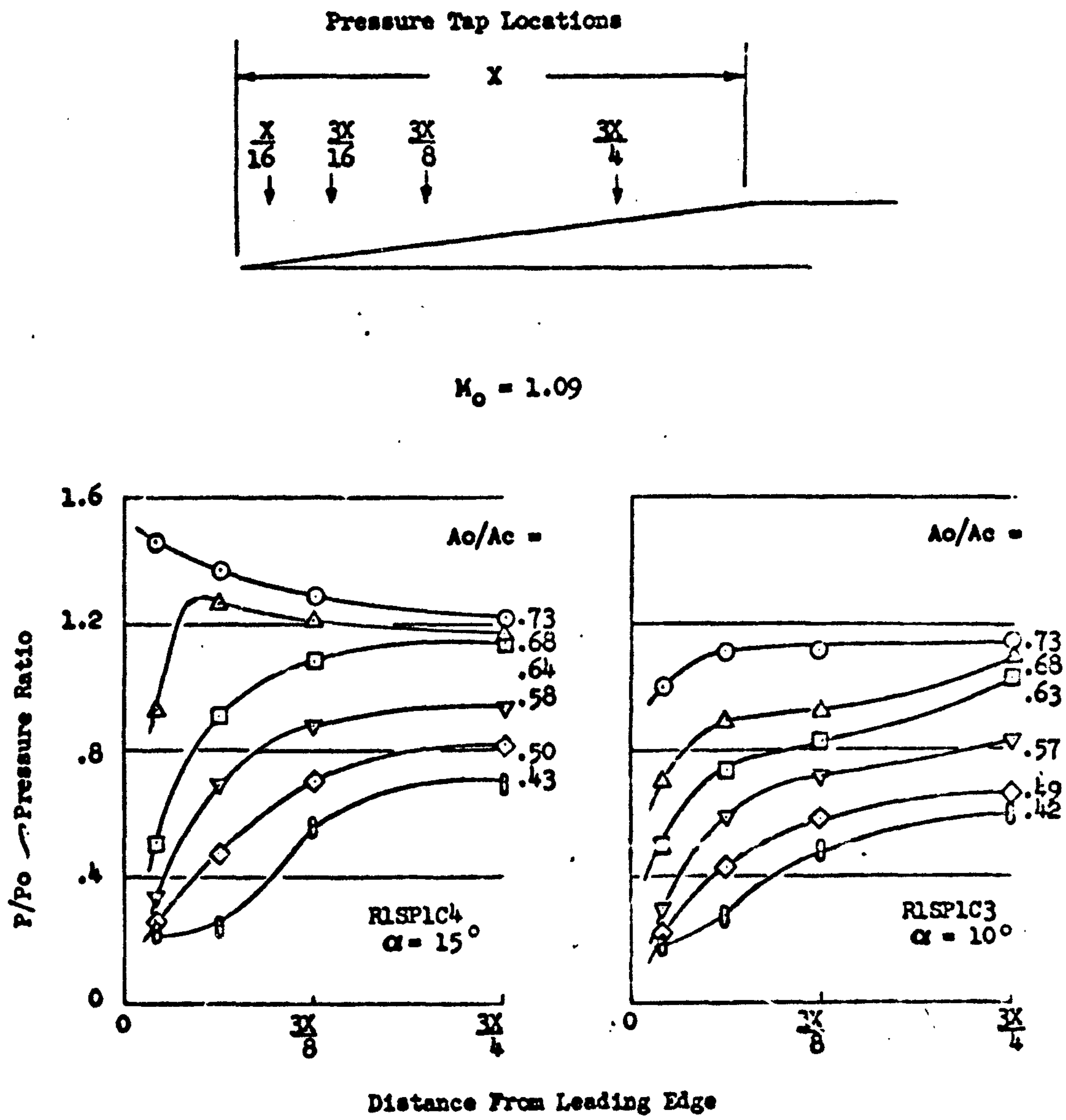


Figure 95. Cowl Centerline Pressure Distributions

CONFIG.	$\alpha°$	$\beta°$	Mo	(A_o/A_c) ref.
R1SP1C1	5°	5°	0.69	0.796
SP2	"	"	0.69	0.796
SP3	"	"	0.71	0.796

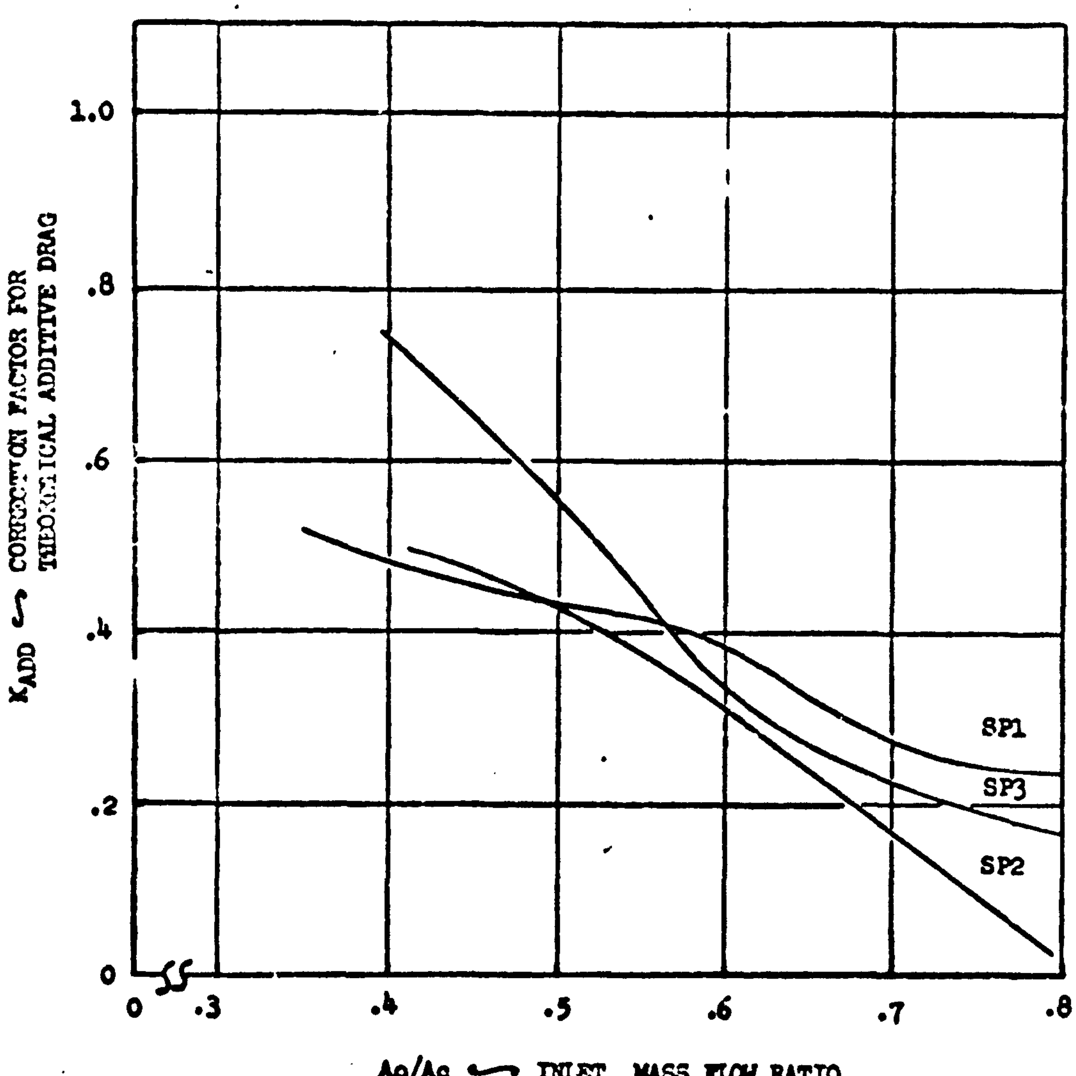


Figure 96. K_{ADD}, SEVERAL SIDE PLATES, Mo = 0.7

CONFIG.	α°	β°	Mo	(Ao/Ac) ref.
R1SP1C1	5°	5°	0.84	0.796
SP2	"	"	0.84	"
SP3	"	"	0.865	"

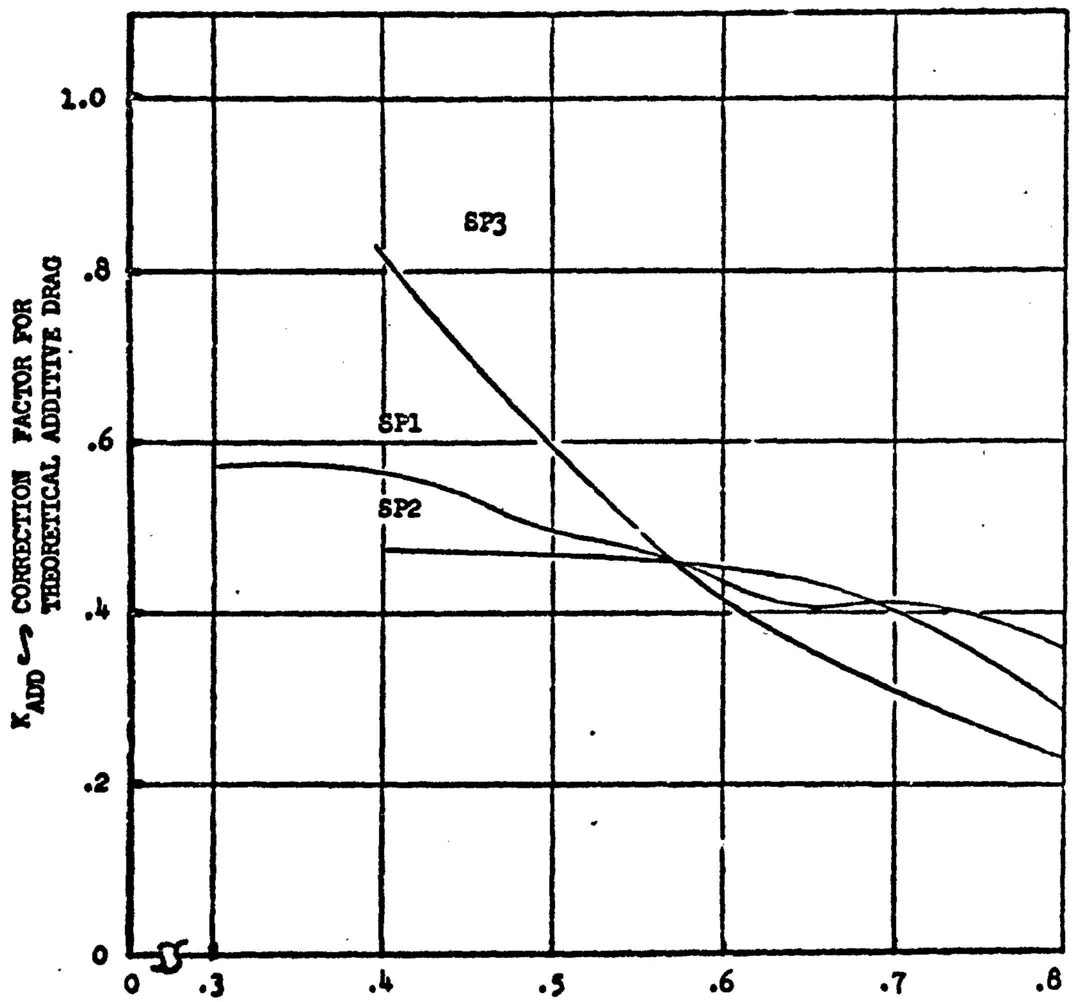


Figure 97. K_{ADD}, SEVERAL SIDE PLATES, M_0 = 0.85

CONFIG.	α°	β°	Mo	(A_o/A_c) ref.
R1SP1C1	5°	5°	1.09	0.796
SP2	"	"	1.09	"
SP3	"	"	1.11	"

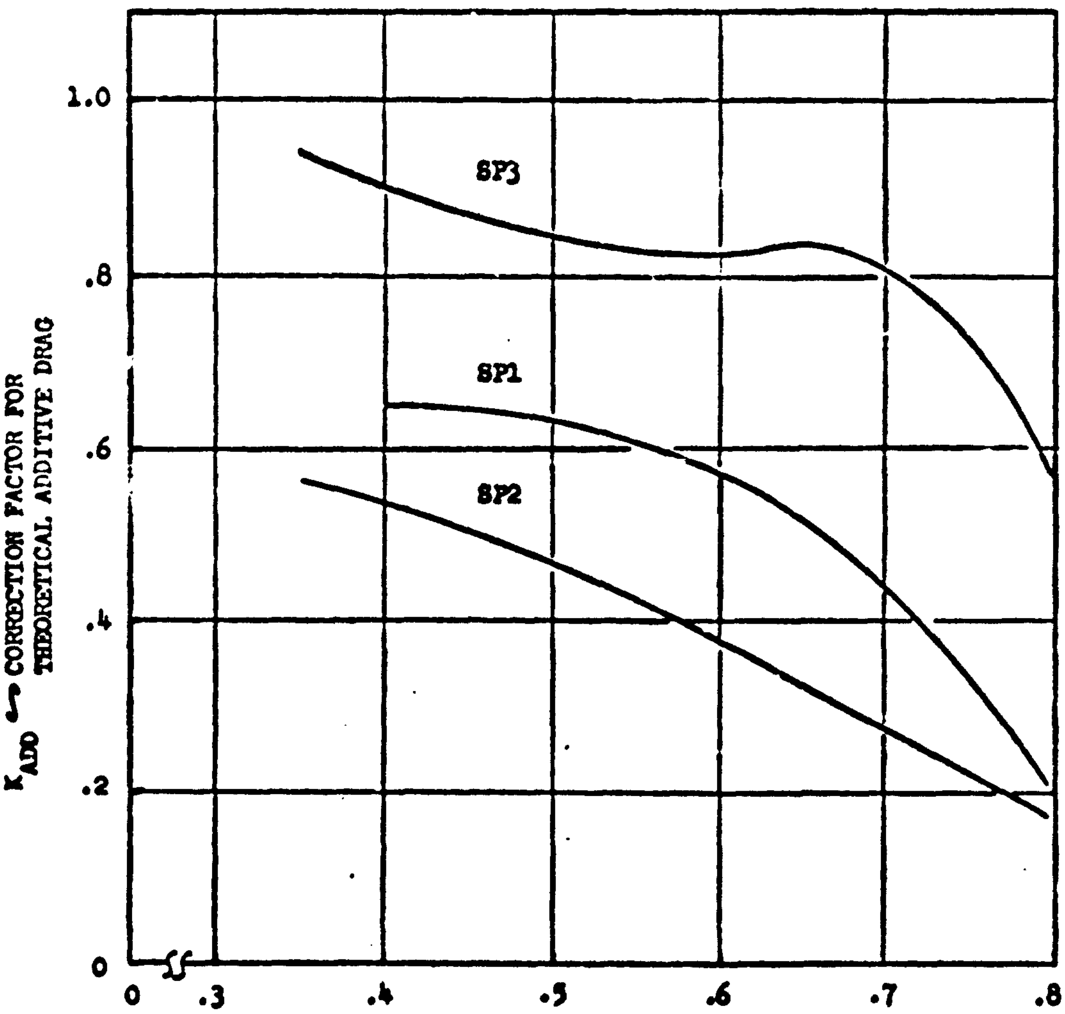


Figure 98. K_{ADD}, SEVERAL SIDE PLATES, Mo = 1.1

CONFIG.	$\alpha°$	$\beta°$	Mo	(Ao/Ac) ref.
R1SP1C1	5°	5°	1.29	0.730
SP2	"	"	1.29	0.75
SP3	"	"	1.31	0.84

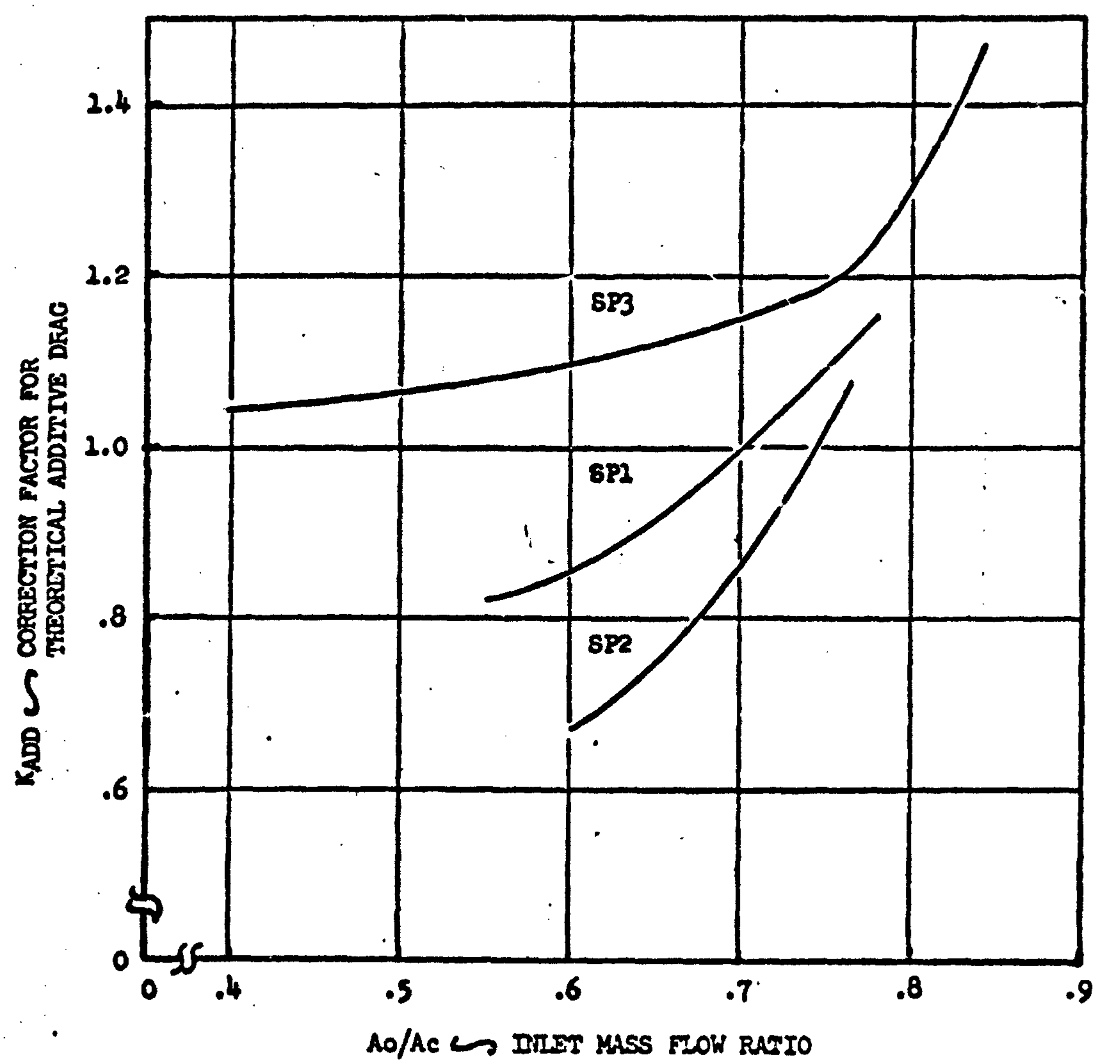


Figure 99. K_{ADD}, SEVERAL SIDE PLATES, $M_0 = 1.3$

CONFIG.	$\alpha°$	$\beta°$	Mo	(Ao/Ac) ref.
R1SP1C1	5°	5°	1.39	0.799
SP2	"	"	1.39	0.767
SP3	"	"	1.41	0.856

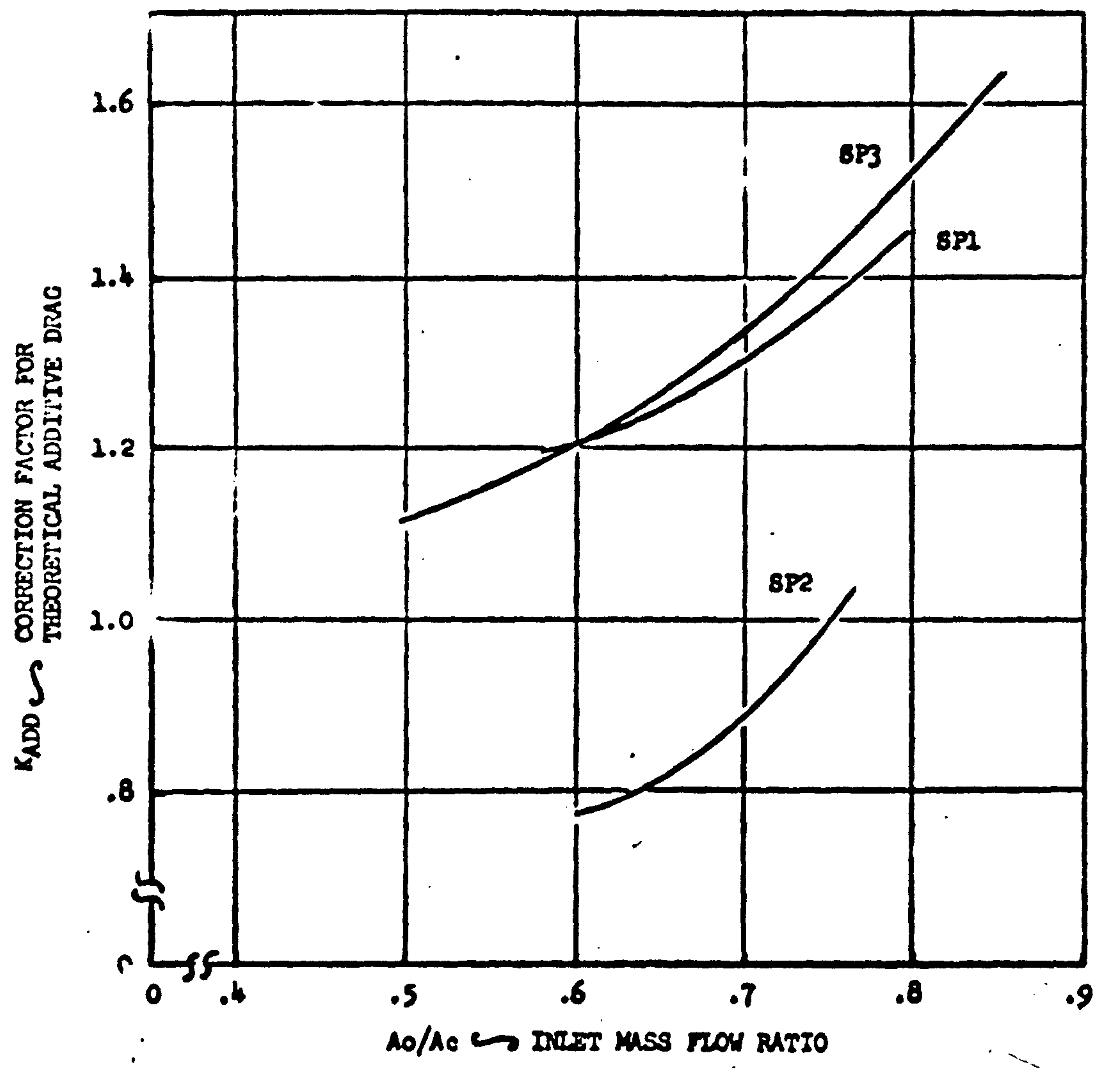


Figure 100. K_{ADD}, SEVERAL SIDE PLATES, M_0 = 1.4

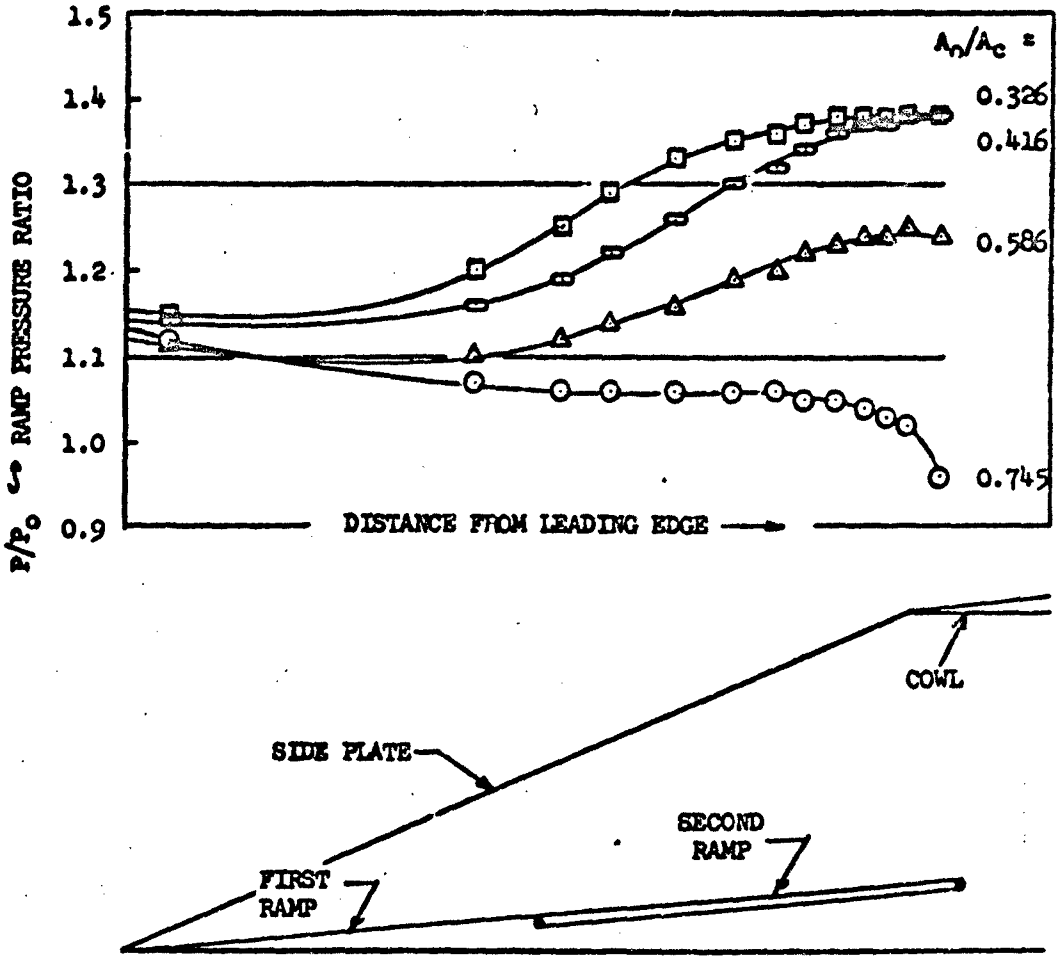


Figure 101. RAMP PRESSURE DISTRIBUTION

R1SP1C1; $\alpha = \beta$ 5°; $M_0 = 0.84$

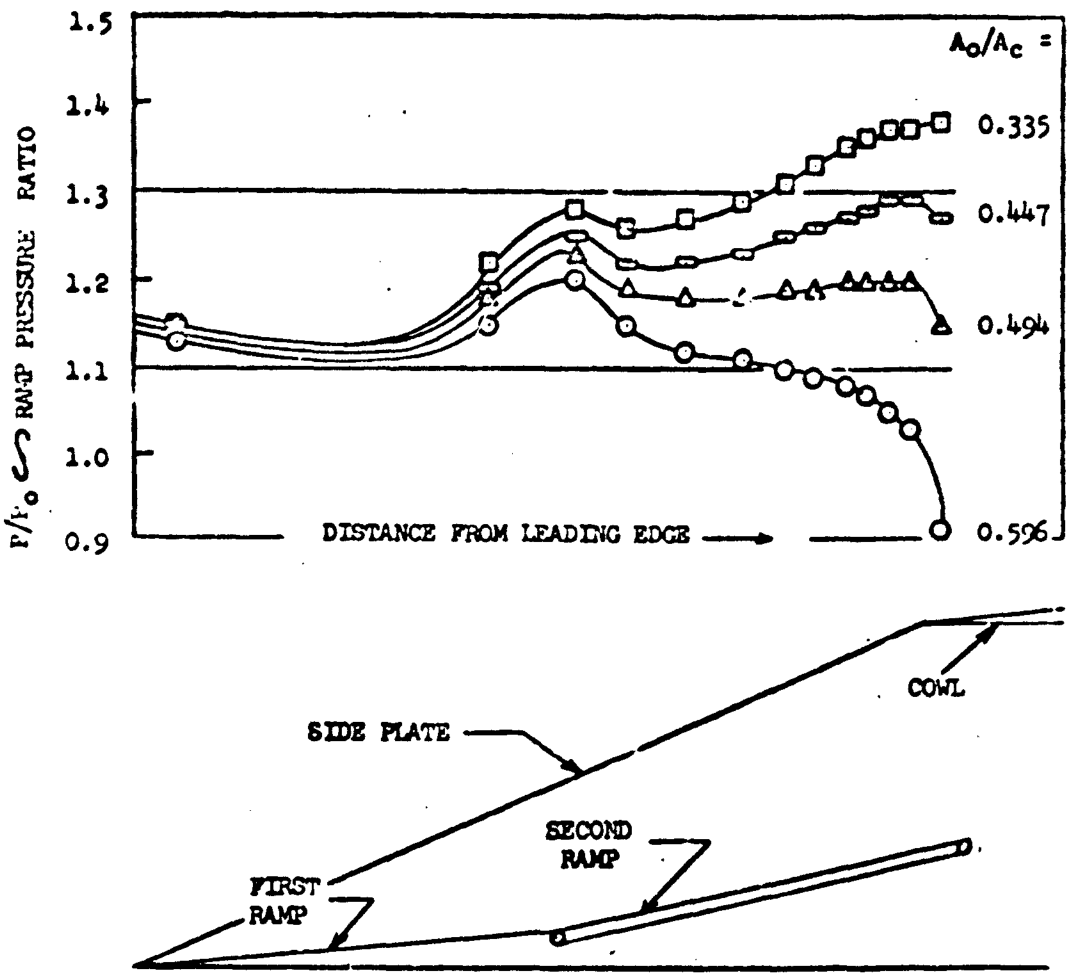


Figure 102. RAMP PRESSURE DISTRIBUTION

N1SP1C1; $\alpha = 5^{\circ}$, $\beta = 12^{\circ}$; $M_0 = 0.84$

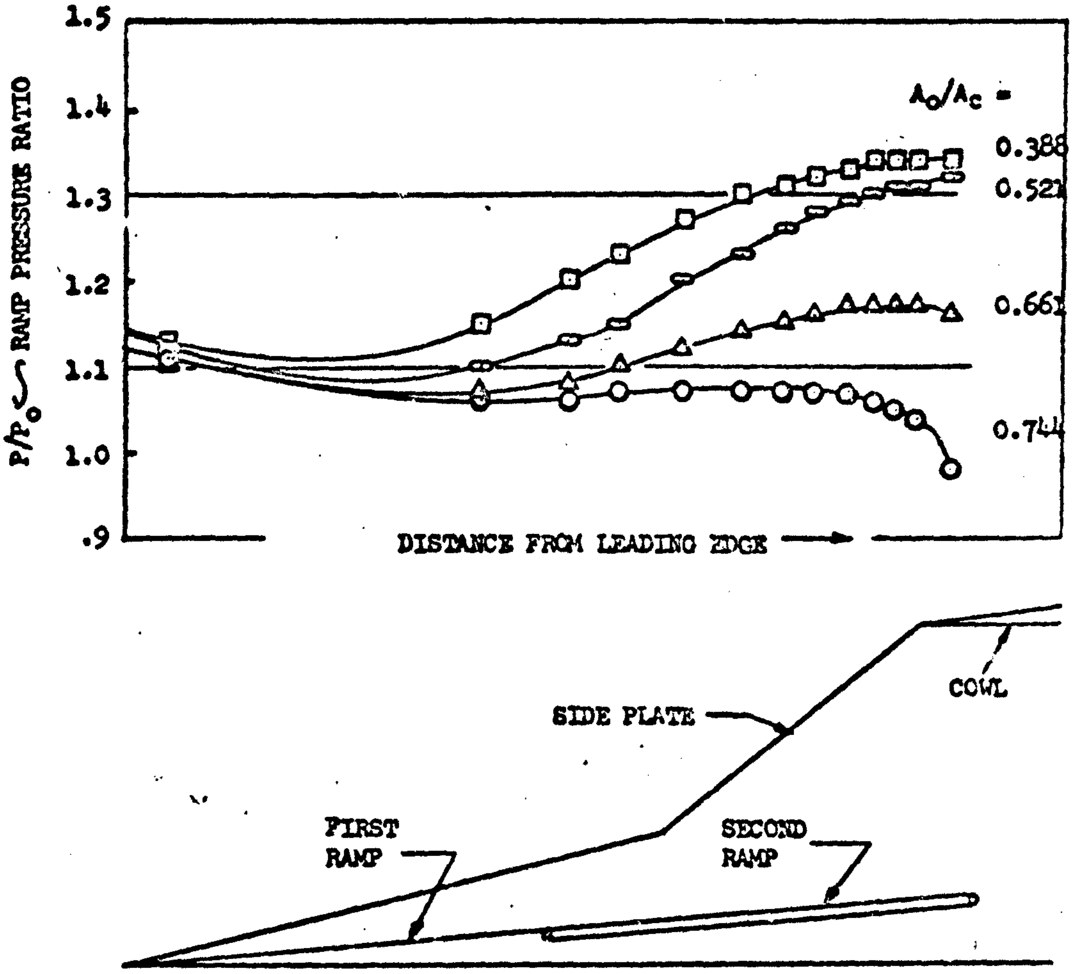


Figure 103. RAMP PRESSURE DISTRIBUTION

R1SP2C1; $\alpha = \beta = 5^\circ$; $M_o = 0.34$

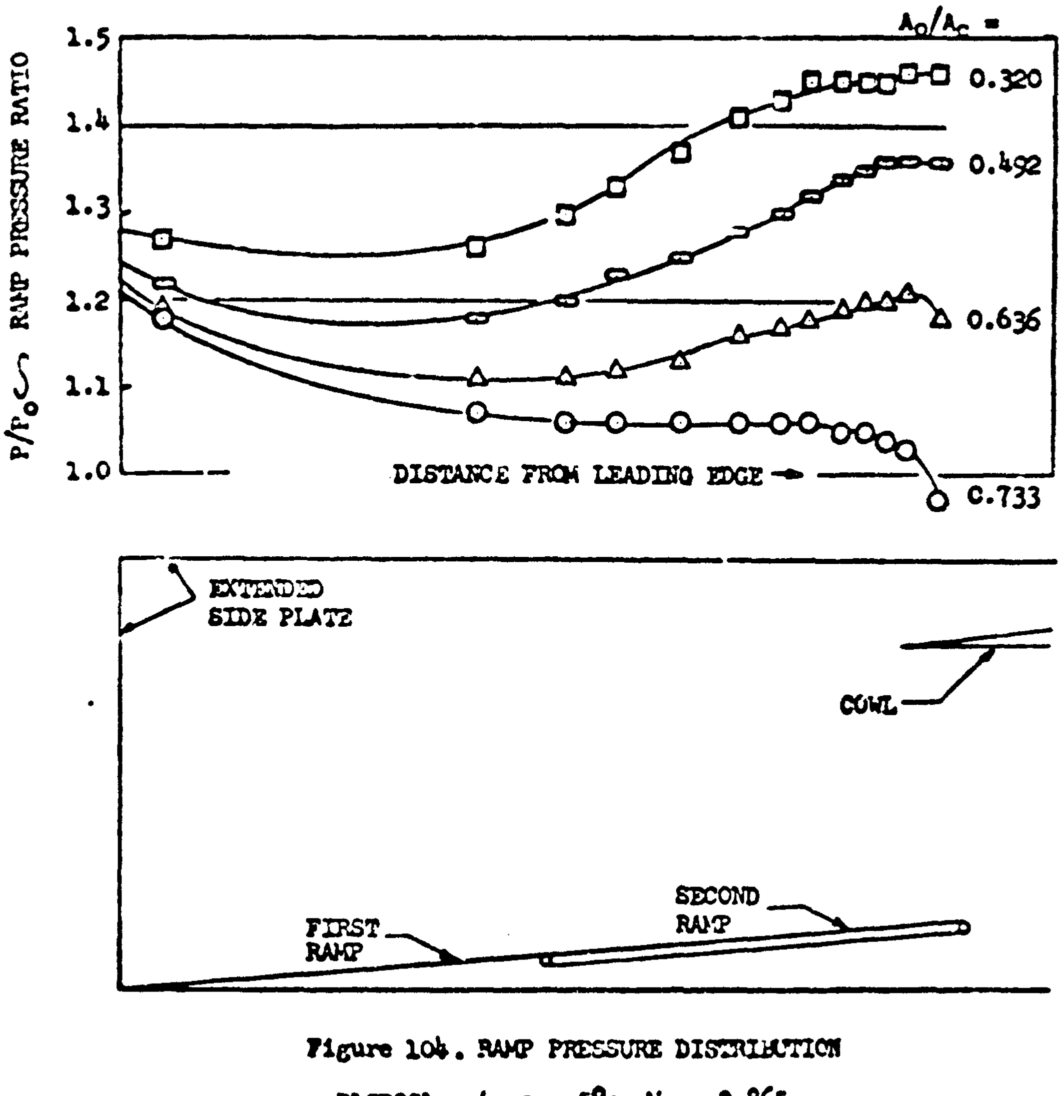


Figure 104. RAMP PRESSURE DISTRIBUTION

R1SP3C1; $\alpha = \beta = 5^\circ$; $M_o = 0.865$

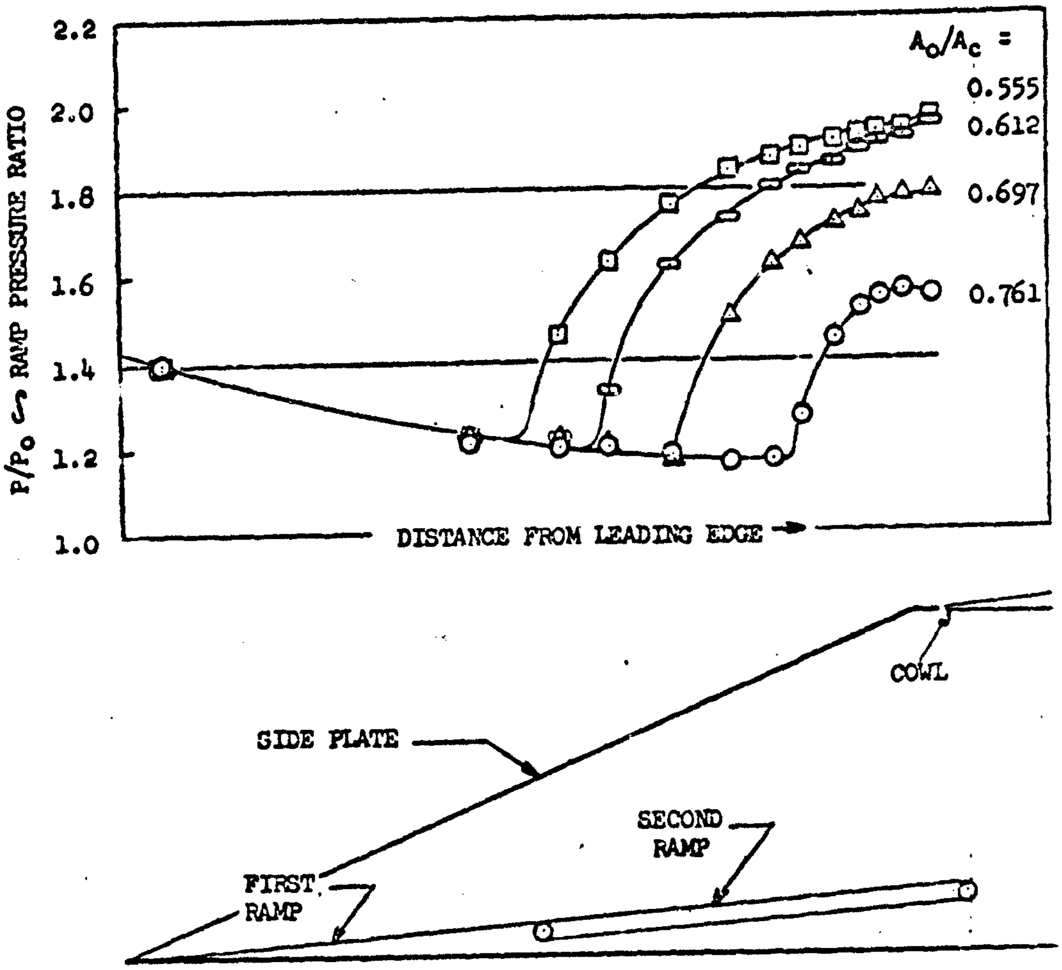


Figure 105. RAMP PRESSURE DISTRIBUTION

R1SP1C1; $\alpha = \beta = 5^{\circ}$; $M_0 = 1.29$

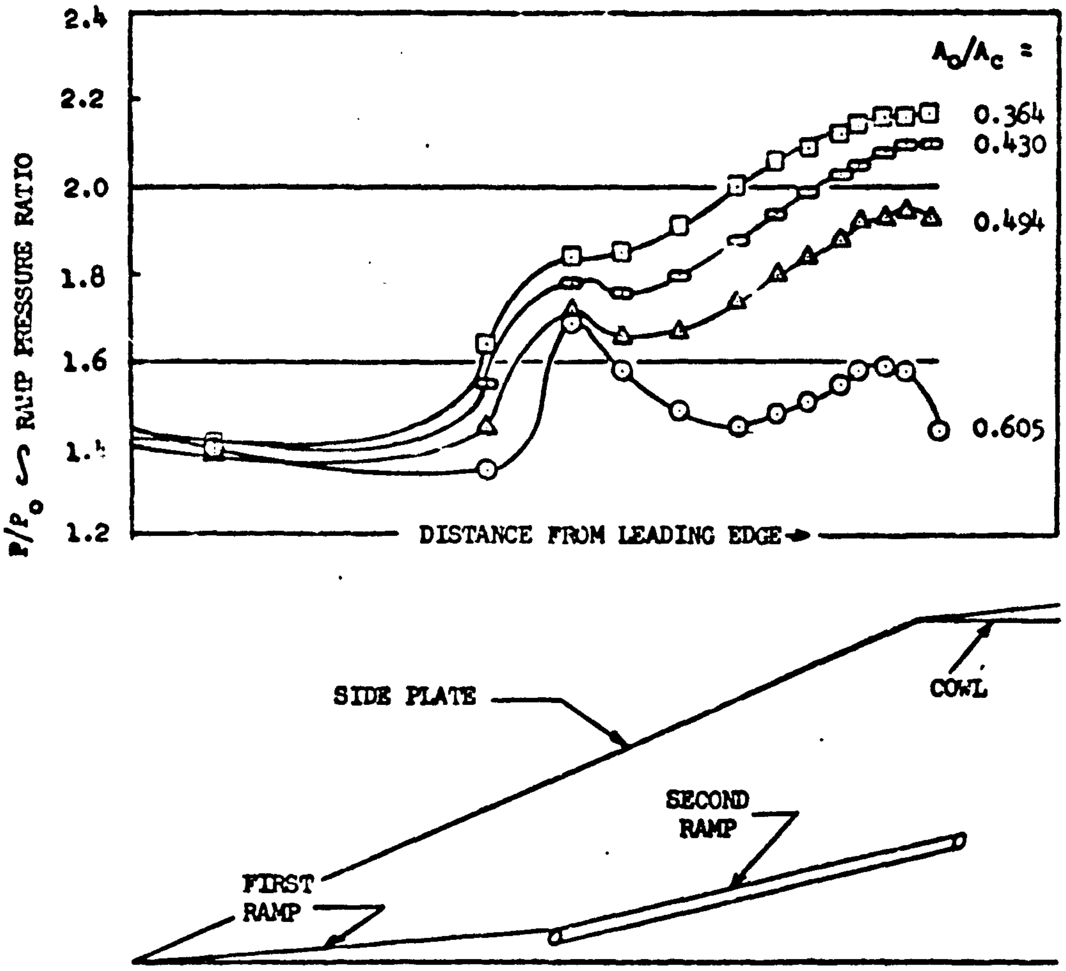


Figure 106. RAMP PRESSURE DISTRIBUTION

R1SP1C1; $\alpha = 5^\circ$, $\beta = 12^\circ$; $M_o = 1.29$

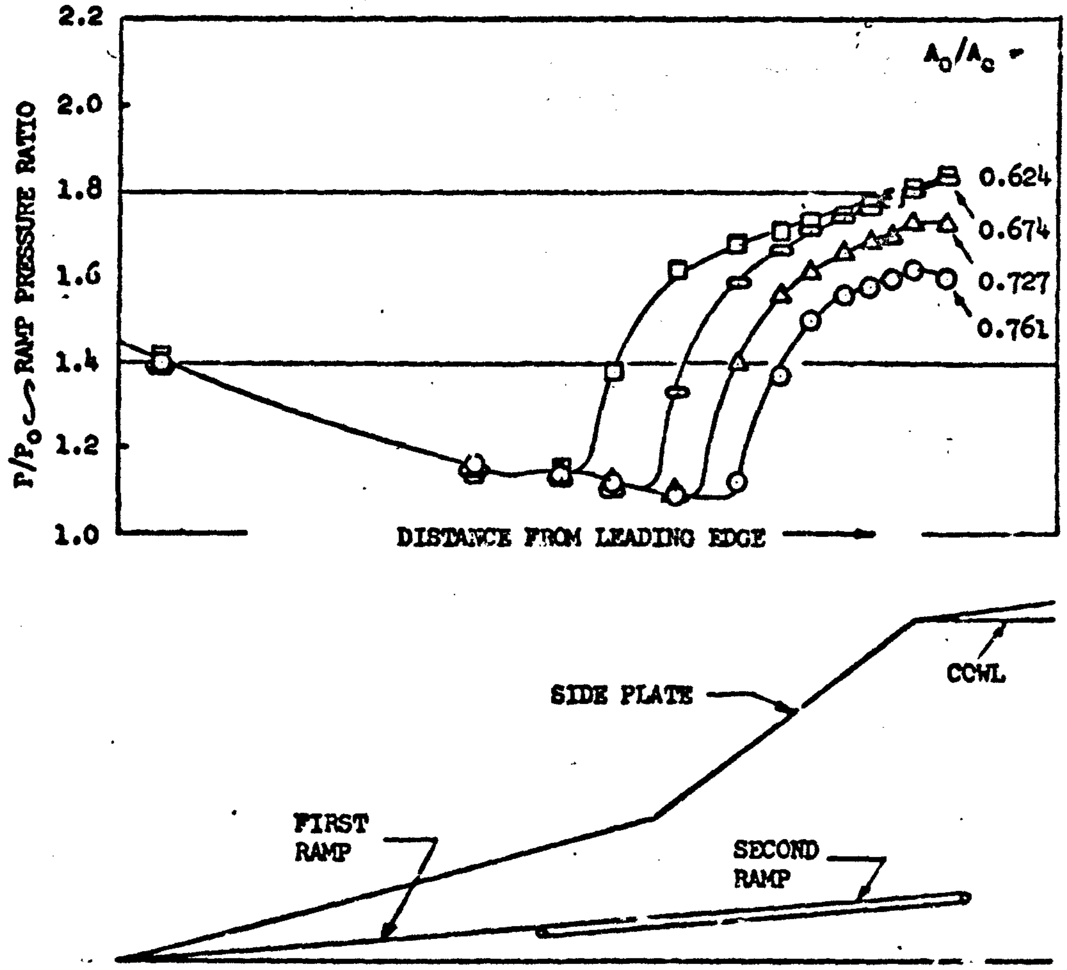


Figure 107 RAMP PRESSURE DISTRIBUTION

R1SP2C1; $\alpha = \beta = 5^{\circ}$; $M_o = 1.29$

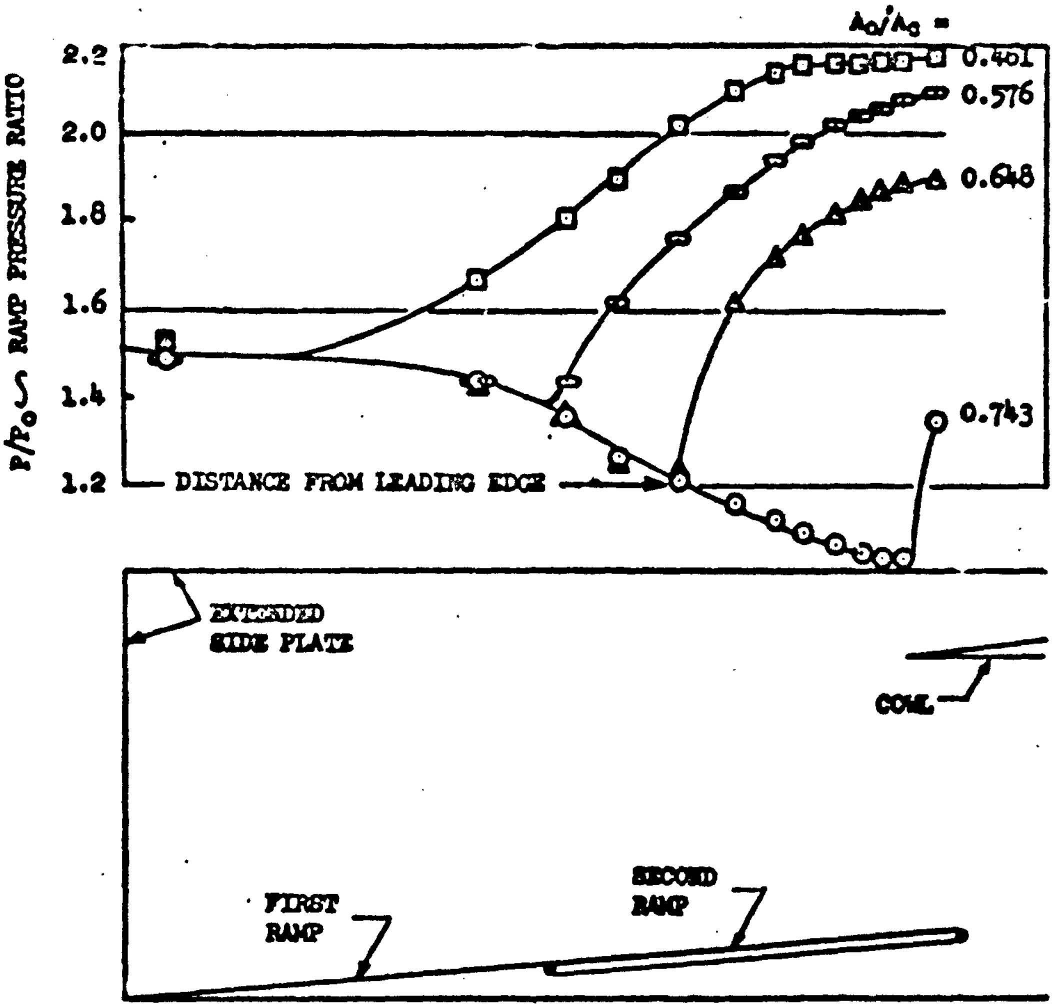


Figure 108 RAMP PRESSURE DISTRIBUTION

R1SP3C1; $\alpha = \beta = 5^{\circ}$; $M_0 = 1.31$

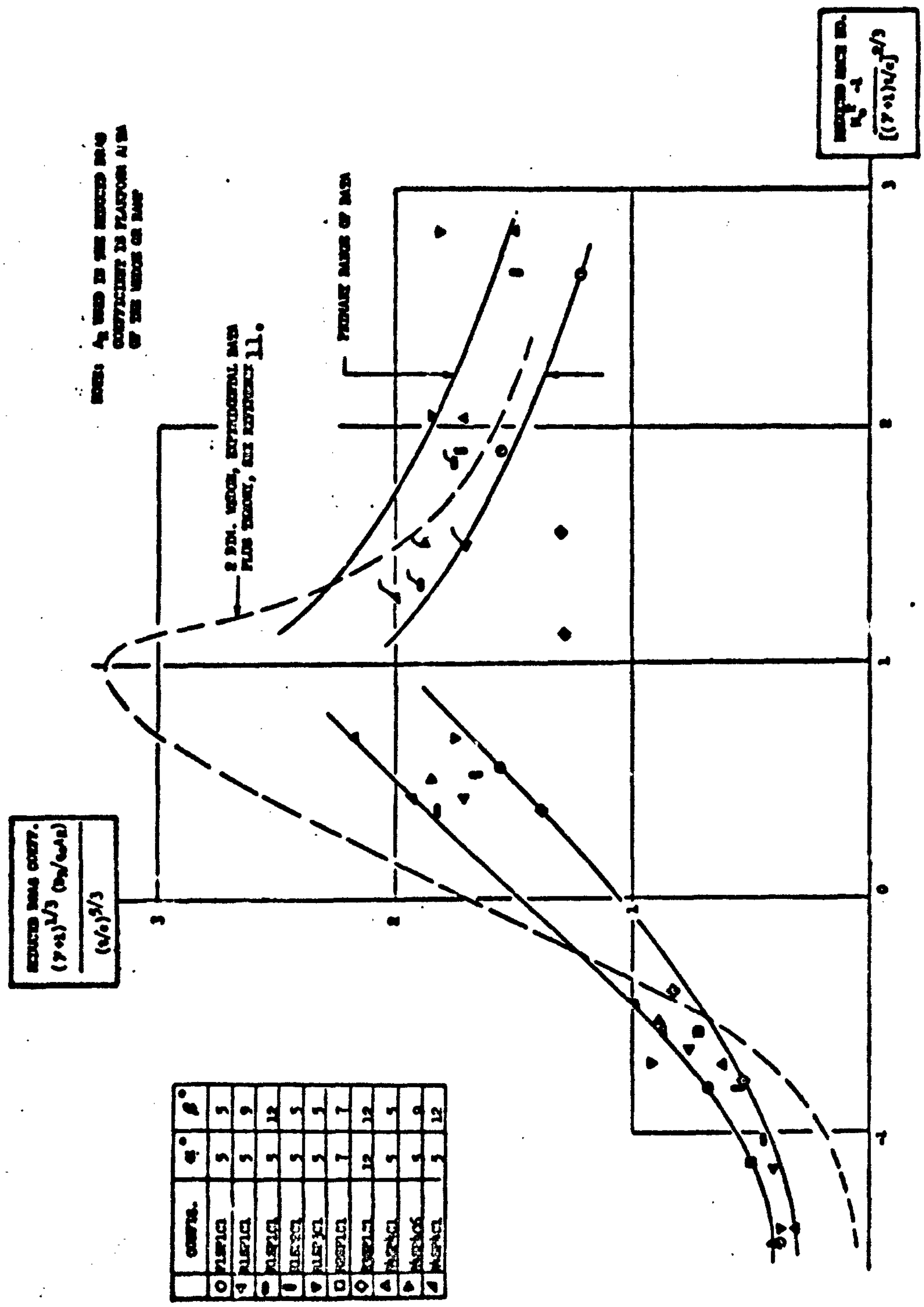


Figure 109. SUGGESTED REFERENCE RAMP DRAG, $(D_R)_{REF}$

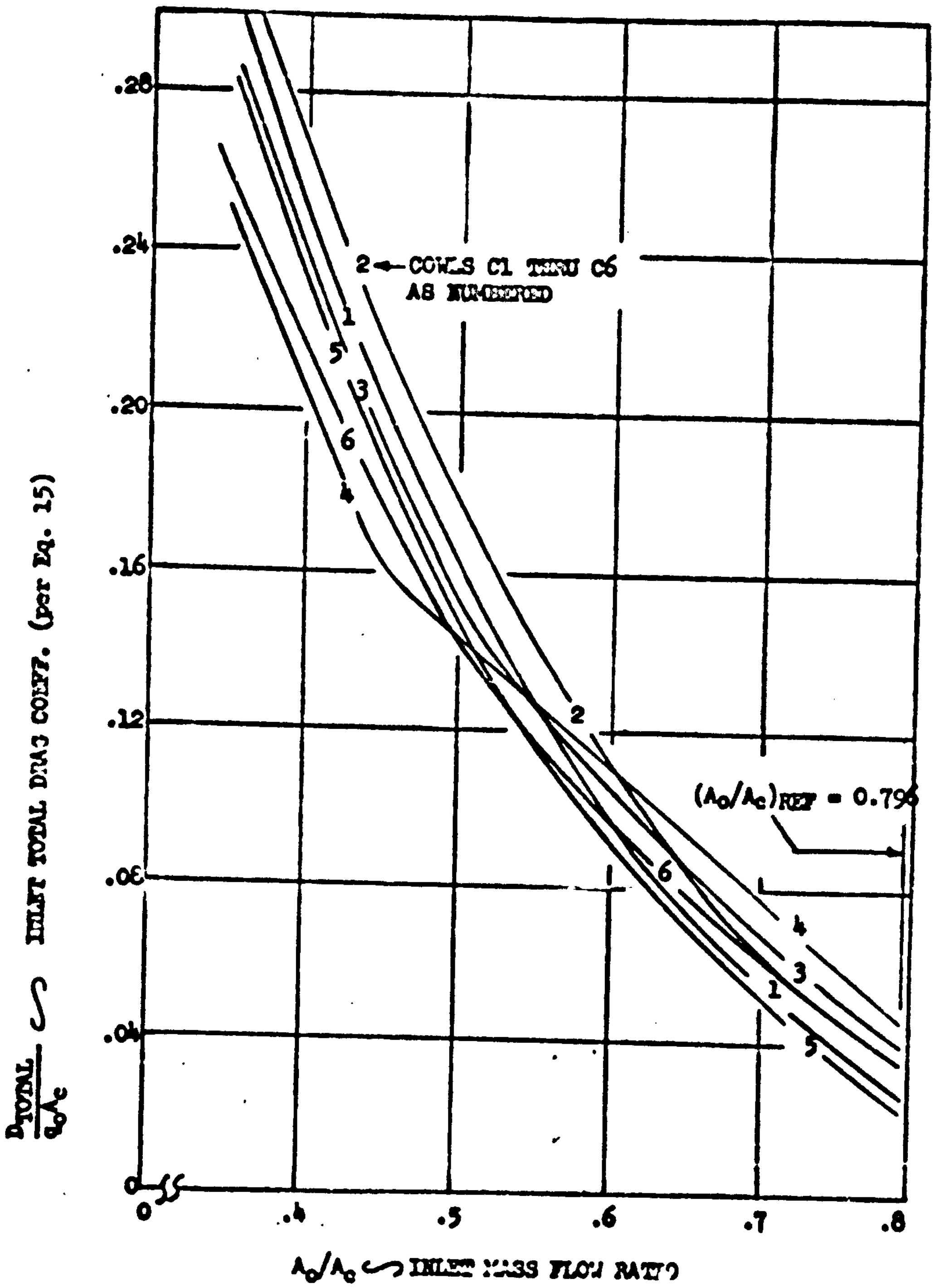


Figure 110. INLET TOTAL DRAG, N1SP1C1 - C6, M_o = 0.84

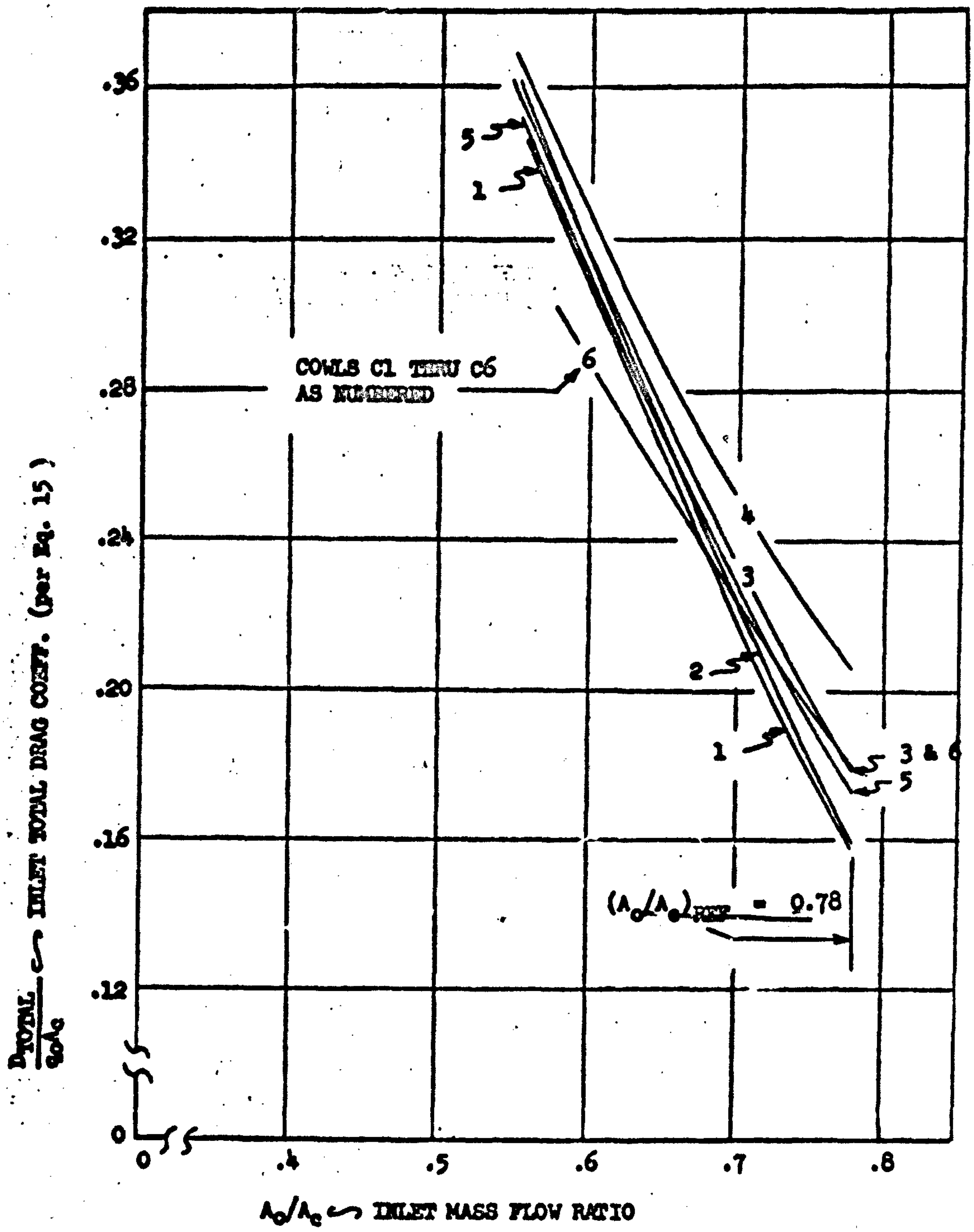


Figure 111. INLET TOTAL DRAG, R1SP1C1 - C6, M_o = 1.29

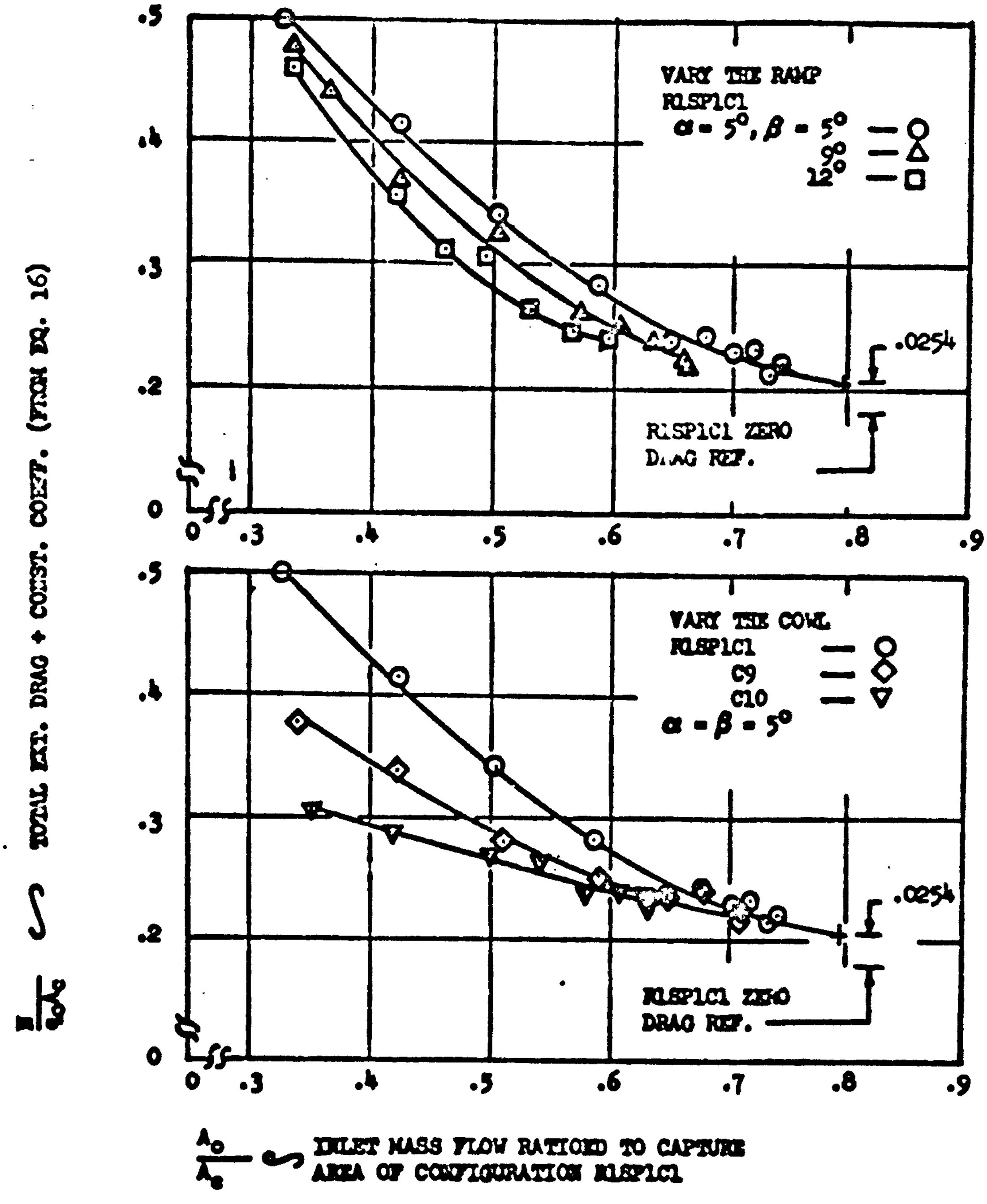


Figure112. SPILLAGE BY VARYING RAMP AND COWL, $M_0 \approx .85$

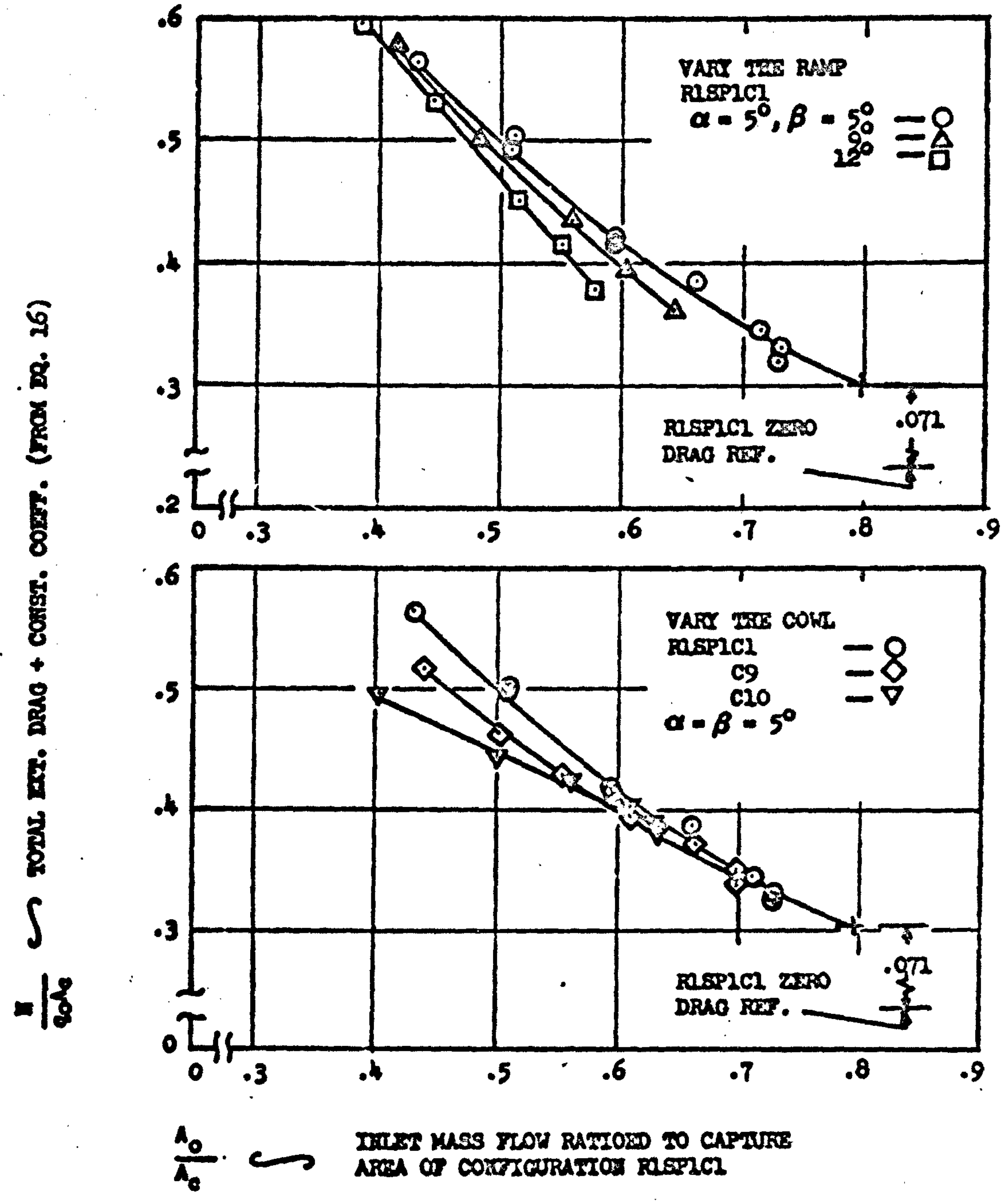


Figure 113. SPILLAGE BY VARYING RAMP AND COWL, $M_0 \approx 1.1$

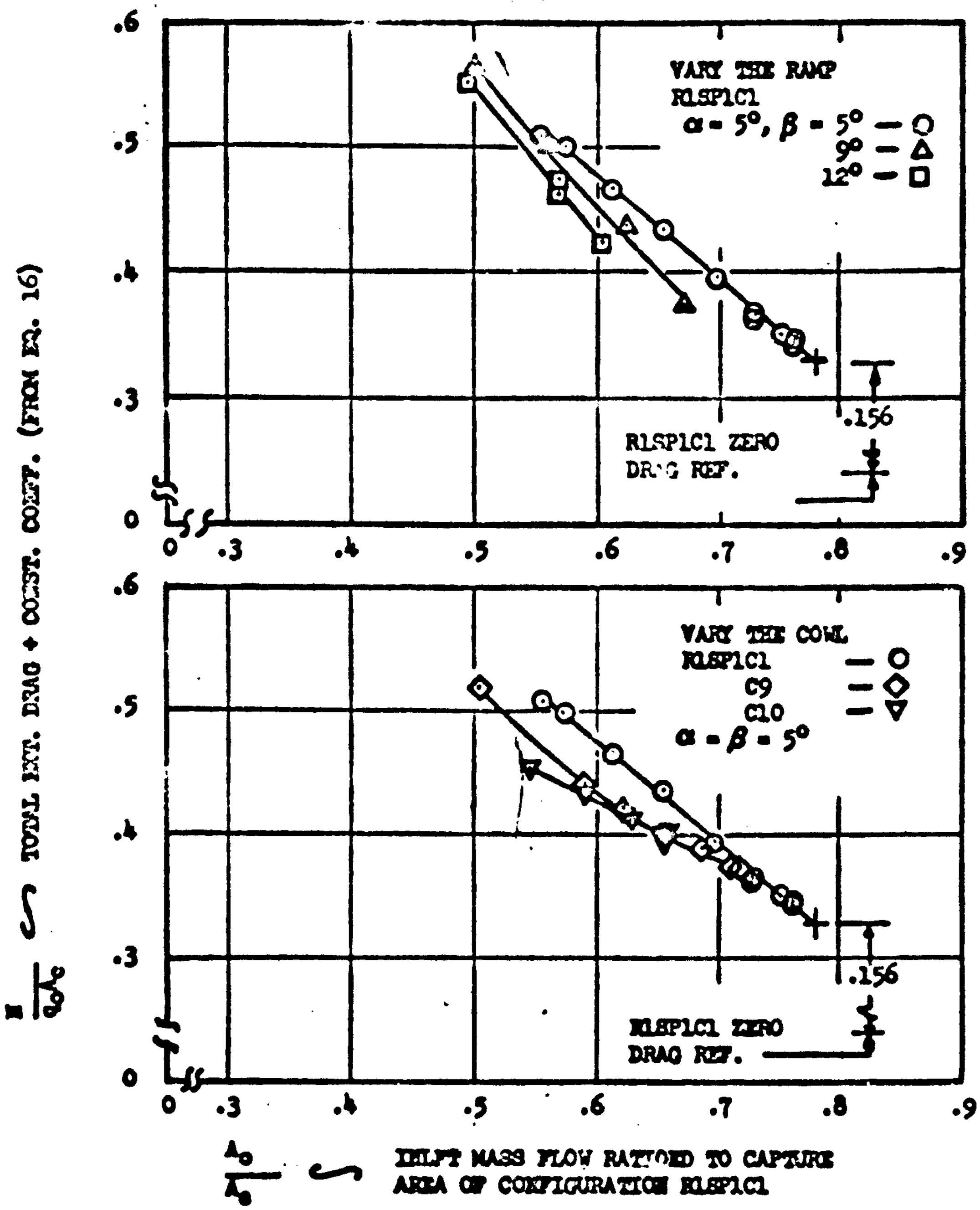


Figure 114. SPILLAGE BY VARYING RAMP AND COWL, M_0 = 1.3

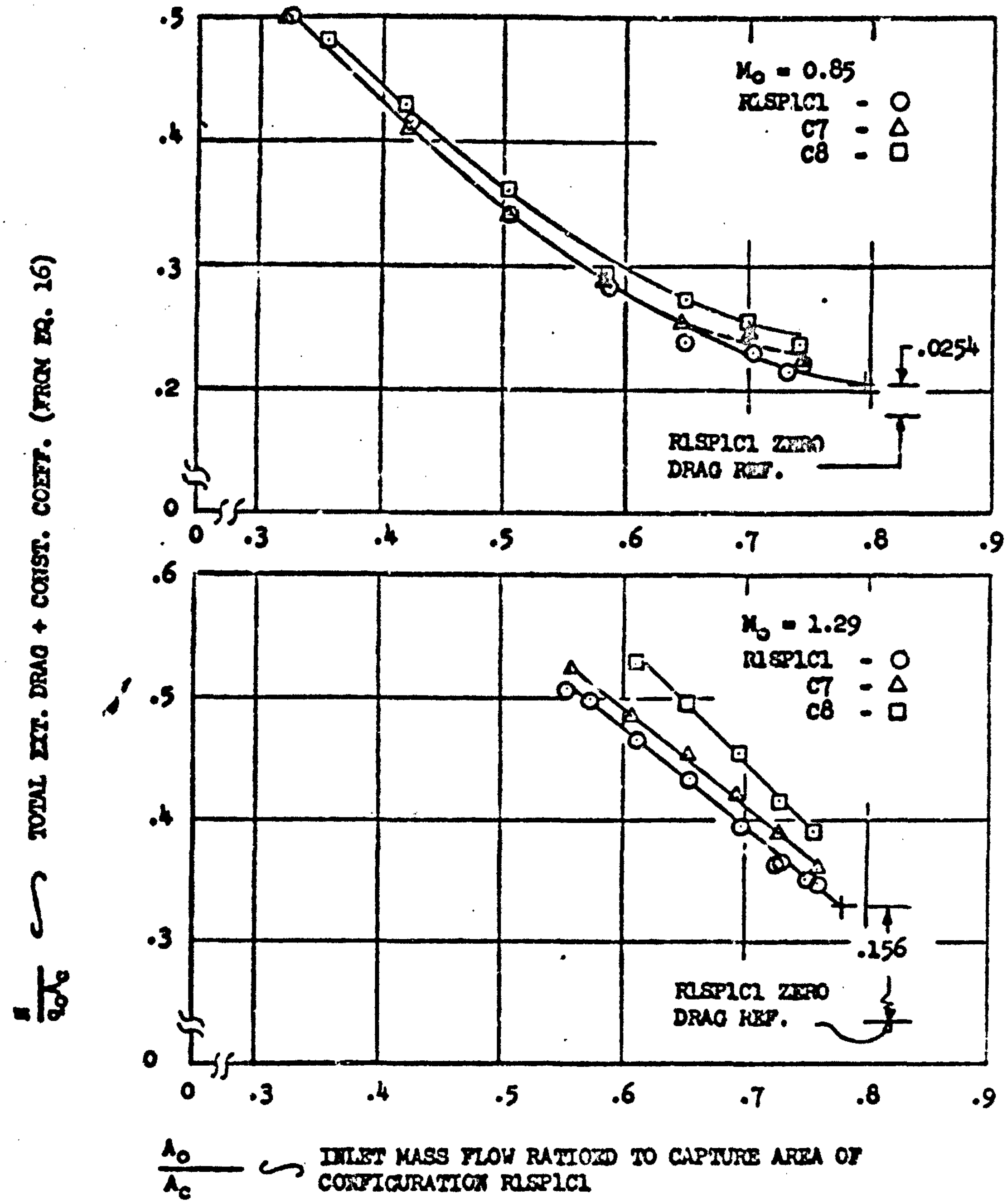


Figure 115. DRAG COMPARISON, SHARP vs. BLUNT COWLS, M_o = 0.85, 1.29

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Air Force Aero Propulsion Laboratory Research and Technology Division Air Force Systems Command Wright-Patterson Air Force Base, Ohio

13. ABSTRACT Inlets sized for supersonic aircraft operation are oversized at transonic speeds. Spilling excess air around the inlet creates spillage drag which can seriously penalize the low altitude penetration range of mixed mission aircraft. Spilling, also, creates inlet cowl lip suction forces which can cancel a portion of this drag, but available data on spillage drag and its partial recovery on the cowl lip were not sufficient for necessary design and performance studies. Generalized wind tunnel studies of inlet spillage were required to supply the needed information.

In 1964, NAA/LAD designed and built a "workhorse" model for in-house tests of pitot inlet spillage drag. Under contract AF33(615)-2496, the "workhorse" portion of this model was fitted with rectangular supersonic inlets. Wind tunnel tests were conducted and are reported herein. Testing was done in the NASA Ames Research Center's 6'x6' Supersonic Wind Tunnel, primarily in the 0.7 to 1.4 Mach number range. The model had four interchangeable ramps, four sets of side plates and ten interchangeable cowls.

Low drag flow spillage requires decreasing the inlet flow area by (a) increasing the external ramp angle or (b) rotating the cowl inward. Test data show that ramp spillage creates lower total drag. The minimum spillage drag configuration would use minor deflections of both ramp and cowl. However, the cowl actuation weight penalty must be considered.

Experimental transonic ramp pressure drags were normalized and compared with transonic similarity work on wedge airfoils. These ramp drag data, together with cowl drag and spillage drag correction (K_{ADD}) factors developed in this report, are valuable tools for inlet design and performance studies.

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Additive drag						
Transonic additive drag						
Rectangular inlets						
Wind tunnel test						

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